

Avalanche

avalanche - a large mass of snow, ice, etc., detached from a mountain slope and sliding or falling suddenly downward. Also called snowslides.

SNOW AVALANCHE

It is estimated that **100,000** snow avalanches occur each year, yet only about 10,000 snow avalanches are reported.

Avalanches need a steep slope, snow cover, a weak layer in the snow cover, and a trigger.

In Wellington, Washington in 1910, an avalanche derailed two trains, killing **96 people**.

The greatest avalanche threats are in the mountainous areas of the Western United States including Alaska.

Over the past 30 years, on average each year, 144 persons have been trapped; resulting in 14 injured and 14 dead. The number of deaths attributed to avalanches each year is exceeded only by floods, lightning, tornados and extreme heat.

The estimated annual average structure damage is **\$500,000**. The estimated annual impacts and costs of all factors is greater than **\$5 million**.

If conditions are right, avalanche releases can reach maximum velocities of **157 mph**.

Avalanches are triggered by natural causes or human actions. Natural causes include earthquakes, thermal changes, and blizzards. Ice slabs falling off cornices may trigger avalanches.

Human activities, such as snowmobiling, snowboarding, skiing, hiking, driving or setting off explosions may trigger an avalanche. Loss of life of backcountry skiers, snowboarders, backpackers, climbers, and snowmobilers due to suffocation is the principal danger.

In Vail, avalanche hazard zones are incorporated in the comprehensive plan and is one of the tools used in evaluating development proposals.

There were 114 reported deaths in Colorado attributed to avalanches from 1985/86-2003/04.

(Sources: FEMA 1997; Mears 1979; Mears 1992; www.caic.state.co.us/facts.html)

Local emergency managers that responded from the west and northwest regions, when averaged, rated avalanche as a moderate hazard. Other regions, when responses were averaged, ranked it as low. The Colorado Department of Transportation ranked it as a high probability of occurrence and a high cost, especially with respect to highway infrastructure; four other state agencies ranked it as moderate probability and moderate cost with respect to their areas of concern. The Department of Transportation has an avalanche program, as described in the 'State Assessment'. The Colorado Geological Survey & CDOT have the Colorado Avalanche Information Center, as described in the 'State Assessment'.



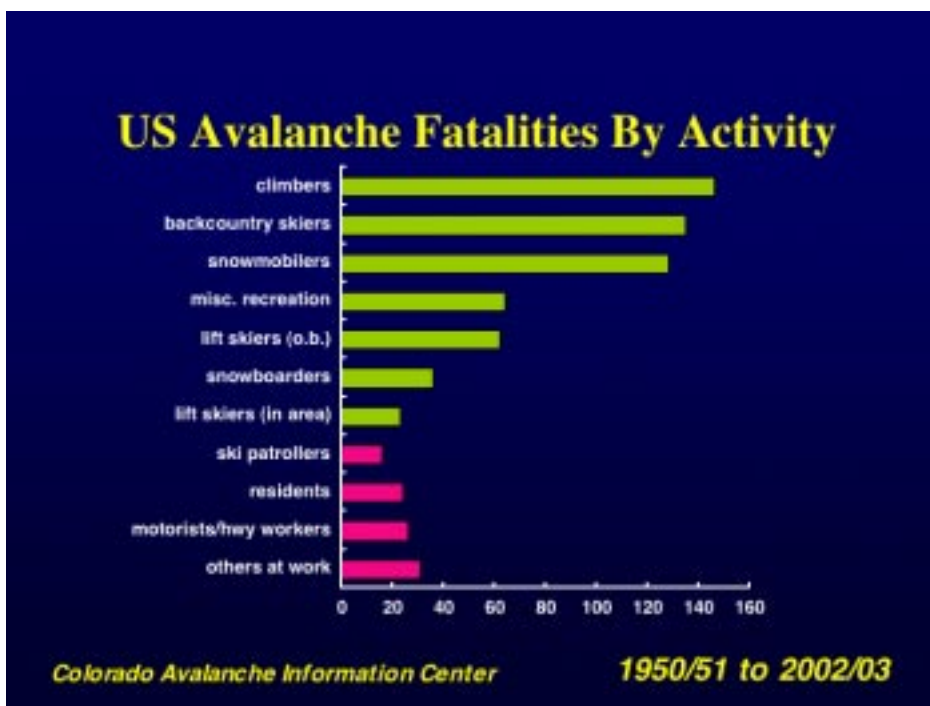
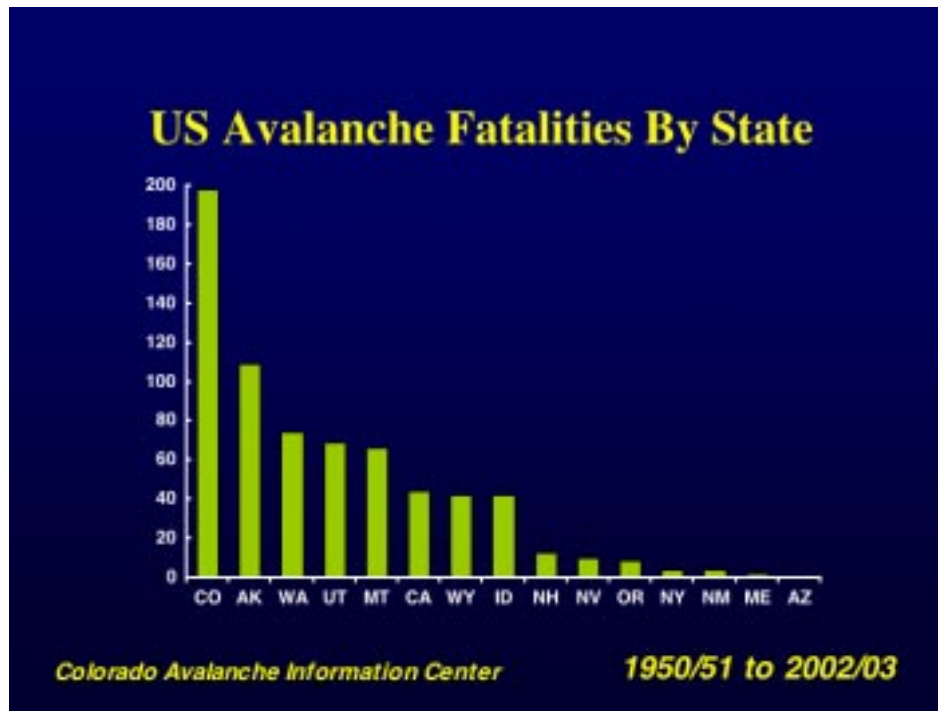
Avalanche mitigation at Arapahoe Basin along Highway 6 just north of Loveland Pass
Photo by CDEM

DAMAGE RELATED TO AVALANCHE IMPACT PRESSURES	
IMPACT PRESSURE (lbs/ft ²)	POTENTIAL DAMAGE
40-80	Break windows
60-100	Push in doors, damage walls, roofs
200	Severely damage wood frame structures
400-600	Destroy wood-frame structures, break trees
1000-2000	Destroy mature forests
>6000	Move large boulders
Sources: Mears 1992; FEMA 1997	

AVALANCHE HAZARD IN THE UNITED STATES

The following graph depicts the number of avalanche deaths by state for winter seasons 1950/51 to 2002/03. Colorado leads the country with deaths attributed to avalanches during this time period. As shown in the graph at the bottom of the page, statistics show that from 1950/51-2002/03 most deaths occurred during climbing activities.

Statistics gathered from 1985-2000 show that most avalanche deaths in the United States occurred from riding a snowmobile. For more information, refer to the Colorado Avalanche Information Center's website at http://geosurvey.state.co.us/avalanche/US_World_stats/summary/1950-2003/state03.html.



SNOW AVALANCHE HAZARD IN COLORADO

The Colorado Geological Survey mapped areas susceptible to avalanche activity. Refer to Special Publication 7, Colorado Avalanche Area Studies and Guidelines for Avalanche-Hazard Planning, published in 1979. Plates are included for the following hazard zones areas:

- Aspen area, Pitkin County
- Camp Bird area, Ouray County
- Crested Butte-Gunnison area, Gunnison County (selected zones)
- Frisco area, Summit County
- Henson Creek area, Hinsdale County
- Independence Pass area, Lake & Pitkin Counties
- Marble area, Gunnison County
- Mt. Zion area, Lake County
- Ophir area, San Miguel County
- Rico area, Dolores County
- Rose Cabin area, Hinsdale County
- Sherman area, Hinsdale County
- Silver Plume area, Clear Creek County
- Twin Lakes area, Lake County
- Vail area, Eagle County



Avalanche Area Warning Sign

Photo by David C. Marlin

"... since 1980, avalanches annually cause on average five deaths, five severe injuries, more than \$100,000 in direct property damage, and more than \$1 million in economic losses. Additionally, avalanches block highways 100-200 times per winter."

- From "Avalanche Facts" by the Colorado Avalanche Information Center in *Solving Land-Use Problems*, Colorado Geological Survey 1998

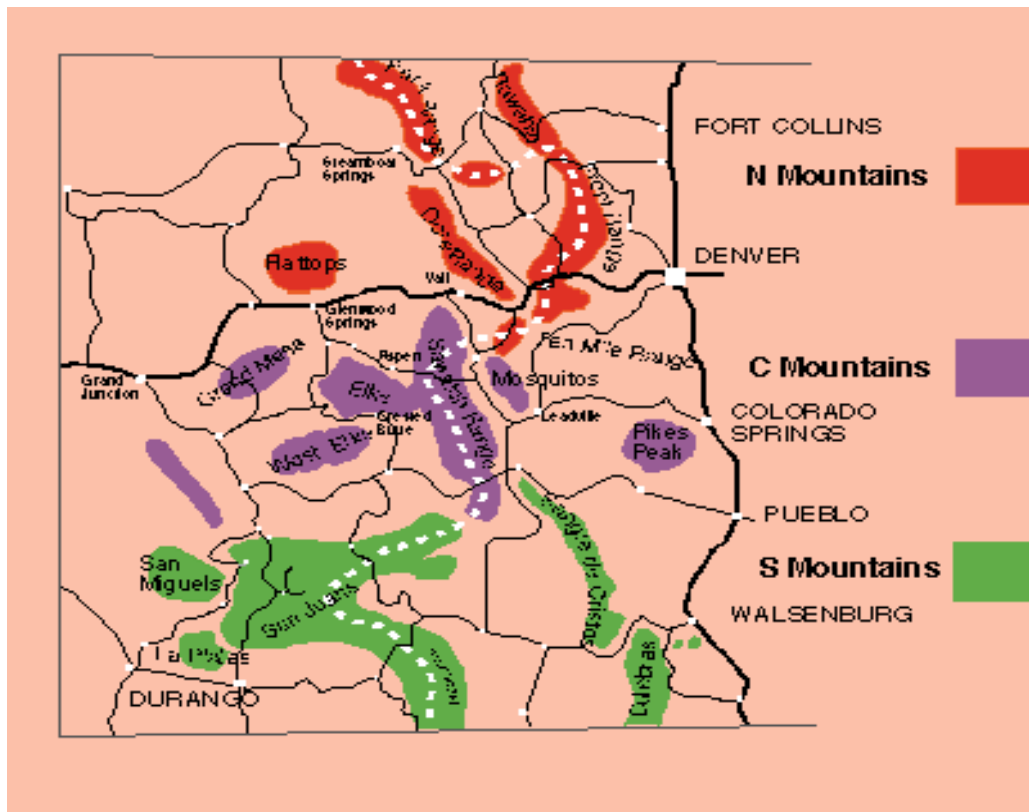
NOTABLE REPORTED AVALANCHE EVENTS IN COLORADO: 1993-2003		
DATE	DESCRIPTION	DEATHS, INJURIES, DAMAGE (M)*
2/17/93 – 2/20/93	Heavy snow. Mountains, southwest. Highest mountain snowfall 60.5". Avalanches triggered. Road closures.	2 injuries; \$50,000 [p]
2/21/93- 2/25/93	Heavy snow. Northern, central, south west mountains, southwest. I-70 avalanche. Cars, truck buried.	\$50,000 [p]
3/26/93- 3/28/93	Heavy snow. Mountains, southwest. Snow to 2'. Avalanche damage.	\$5,000 [p]
10/14/94 - 10/17/94	Heavy snow. Southwest. High winds. Snow totals 1-5'. Avalanches triggered. 200 hunters stranded, lost.	5 injuries; 2 deaths
1/15/95 – 1/18/95	Heavy snow. High country. Snow totals 1-4'. Injuries from avalanches.	4 injuries
2/8/95 – 2/14/95	Heavy snow. Mountains, front range. Mountain snow to 8'. Avalanches, road closures, deaths and damage.	2 deaths \$1.7M [p]
2/20/96- 2/21/96	Heavy snow. Central, northern, south west mountains. Snow to 2'. I-70 20-car pile-up. Avalanches, roads closed.	1 death; 2 injuries
1/21/98	Avalanche. San Bernardo Mountain.	1 death
3/8/98	Avalanche. Ophir Gulch.	1 death
3/29/98	Avalanche. Near Gladstone.	\$75,000 [p]
11/8/98	Avalanche. Telluride Ski Area. Preseason skier triggered avalanche.	1 injury; \$500 [p]
1/23/99	Avalanche. Aspen Highlands Ski Area. Two skiers triggered avalanche.	1 death; 1 injury
1/30/99	Avalanche. Grand Mesa. Human triggered. Snowmobiler buried.	1 death
2/6/99	Avalanche. Cumberland Pass area. Humans triggered avalanche.	3 deaths 1 injury
1/25/00	Avalanche. Hurricane Gulch by Aspen	1 death
3/17/00	Avalanche. Highland Peak.	2 deaths
3/23/03	Avalanche in Clear Creek County. Some damage to Silver Plume water treatment plant's chlorine contact building and tank. Currently planning to rebuild facility elsewhere. I-70 frontage road blocked. Clear Creek dammed up. Utility line down.	

*(M)—millions of dollars; [p]—property damage; [c]—crop damage.
Source: Colorado Division of Emergency Management 2000; www4.ncdc.noaa.gov/cai-win/www.cai.dll?wwevent~storms



Avalanche danger along Highway 6

Photo by CDEM



"Avalanche Regions" Reprinted from <http://www.caic.state.co.us/aviregions.html>

Colorado Fatalities by County

Northern Mtns.

Summit	33
Clear Creek	21
Eagle	9
Grand	6
Larimer	6
Boulder	5
Routt	2
Jackson	2
Rio Blanco	1
Total	85

Central Mtns.

Pitkin	33
Gunnison	17
Chaffee	11
Lake	11
Mesa	2
El Paso	1
Garfield	1
Total	76

Southern Mtns.

Ouray	12
San Miguel	10
San Juan	5
Mineral	4
La Plata	2
Conejos	1
Dolores	1
Hinsdale	1
Montezuma	1
Total	37

Colorado Avalanche Information Center

1950/51 to 2002/03

From CGS Special Publication 12

A **SNOW AVALANCHE** is a mass of snow, ice, and debris; flowing and sliding rapidly down a steep slope.

Characteristics

Snow avalanches occur in the high mountains of Colorado during the winter as the result of heavy snow accumulations on steep slopes. When the snow pack becomes unstable, it suddenly releases and rapidly descends downslope either over a wide area or concentrated in an avalanche track. Avalanches reach speeds of up to 200 miles an hour and can exert forces great enough to destroy structures and uproot or snap off large trees. It may be preceded by an "air blast" which also is capable of damaging buildings.

Avalanche paths consist of a starting zone, a track, and a runout zone. In general the runout zone is the critical area for land use decisions because of its otherwise attractive setting for development. Avalanche-prone lands may pass many winters or even decades without a serious avalanche. Only part of an avalanche may release at once. Lack of vegetation or a predominance of quick-growing aspen and low shrubs often characterize active portions of an avalanche track and the runout zone, readily identifying the seasonal peril. Hundreds of snow avalanches happen each winter, most of them in remote places.



The Battleship (also known as Arnold) is a large path along US 550 in southwestern Colorado. It is located in the San Juan Mountains about 3.55 miles north of Silverton. The top of the starting zone is at 12,400 feet, and avalanches can fall 2720 feet to Mineral Creek, but very large slab avalanches such as this one can climb the 250 feet from the creek to the highway. This avalanche buried US 550 3 feet X 800 feet on February 28, 1987, Red Mountain Pass, Colorado. Photo by Tim Lane.

Consequences

Avalanches are extremely destructive due to the great impact forces of the rapidly moving snow and debris and the burial of areas in the runout zone. Structures not specifically designed to withstand the impacts are generally totally destroyed. Where avalanches cross highways, passing vehicles can be swept away, demolished and their occupants killed. Snow avalanches also imperil cross-country skiers, downhill skiers, and snowmobilers and several of the backcountry visitors perish each winter.

Residences planned or erected in avalanche runout zones may not qualify for financing or insurance.

Snow Avalanches

Aggravating Circumstances

Man's activities frequently trigger avalanche and certainly man's activities create the hazard. The process only becomes a hazard when man interacts adversely with it. Where no structures exist or no recreational activity occurs, avalanches occur with no damage to structures or lives being lost. Building construction in an avalanche path eventually may result in destruction of property and the loss of life. Although most snow slides are initiated by natural causes, skiers frequently trigger the smaller avalanches that take their lives by breaking the snow surface while crossing an area prone to "run". Avalanches can also be triggered by sounds from shouts, machine noises, and sonic booms.

Mitigation

The cheapest and safest way to prevent property damage and save lives is to stay out of avalanche paths and runout zones in winter. Methods of avalanche control include directional control of blowing and drifting snow by erecting snow fences to keep it away from the starting zone; planned release of small snowslides with explosives before the snow accumulation increases their destructive potential to unmanageable proportions; building snow sheds over particularly dangerous sections of railroad and highways. Sometimes diversion structures can divide an avalanche and minimize its impact. Avalanche warnings are common in Colorado, but they do not remove the peril, only alert one to it.

Land Use

In general, land use within an avalanche area should not include buildings intended for winter and early spring occupancy. Ordinarily, use of avalanche areas in the summer and fall constitute no hazard. In some cases, other hazards, such as debris flows, occupy the same area. Non-occupancy structures that are placed in avalanche paths and runout zones

should be designed for expected impacts even if some other preventative measures are implemented. Portions of power lines, highways, railroads and other facilities often have to be built to withstand avalanches.

Case History

Seven persons sleeping in their beds were swept to a frigid doom in a predawn avalanche at Twin Lakes, Colorado, on January 21, 1962. Two persons and a spotted puppy miraculously survived.

The avalanche raced down Gordon Gulch on 12,676-foot high Perry Peak, traveling some 9,000 feet at very high speed over 2,800 vertical feet. It topped a 100-foot high natural barrier and demolished everything in its path including seven buildings and a house trailer. The remains of one house were found 500 feet from the foundation. Two cars, three trucks, two pickup trucks and other equipment were crumpled. State highway 82 was under 8 feet of packed snow and power and telephone lines were ripped out for 1,000 feet.

Many of the victims were still wrapped in their blankets on their mattresses and were buried alive under as much as 12 feet snow. The injured survivors were buried more than four hours before rescue. They were sheltered by debris although still trapped under the snow. Rescuers found hard snow slabs 3 feet across and 18 inches thick that had survived the high-speed trip from near the summit of the peak. The snow was 10 feet deep where it broke away. Enroute it launched two other slides from adjacent tracks. It was later determined that avalanches had topped the 100 foot high glacial moraine at least twice before (in 1899 and 1916), a fact confirmed by counting tree growth rings on large 70-year-old aspen which had been snapped off and carried along by the snow.

While the moraine ordinarily had sheltered the village on the northwest side of Twin Lakes Reservoir, it was inadequate for this very large avalanche. The site of the tragedy is still evident, although nature has begun healing the scars with new vegetation.

Case History

On the afternoon of February 23, 1961, two women left the groomed ski slopes at Aspen to ski in unblemished snow of a small basin near the main ski run. The avalanche hazard was high and warnings had been published and posted.

The experienced skiers whisked out onto the slope and down, intent on skiing toward and then through a small stand of timber. When the first skier reached

the bottom of the slope, her companion had vanished. Less than an hour later the missing skier was found suffocated under three feet of snow from a small avalanche that ran only 90 feet.

Note

These examples are from "The Snowy Torrents, Avalanche Accidents in the United States, 1910-1966," published by the Alta Avalanche Study Center, U.S. Forest Service.

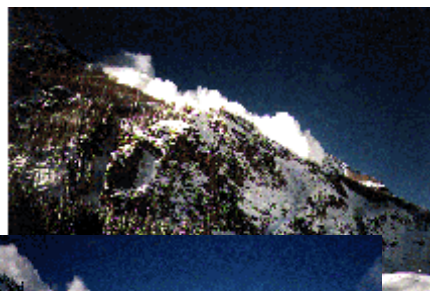
Case History

In 1972, a subdivision near Vail was allowed in an avalanche path not far from the ski area and construction began on condominiums. The builder was stopped after financial institutions withdrew money from the project on learning it was in an avalanche path and mud flow zone. Today the development is but a concrete foundation—a monument that property damage can be prevented and lives saved by responsible action. The geologically hazardous area is now zoned for open space. The case is a landmark example of what can happen when land-use regulations are legally circumvented and the builder's and the public's best interests are ignored.

From CGS Special Publication 6 Definitions

Legal definition

H.B. 1041, Part 1, 106-7-103 (2) "Avalanche" means a mass of snow or ice and other material that may become incorporated therein as such mass moves rapidly down a mountain slope.



West
Riverside,
Red
Mountain
Pass,
Colorado.
Photos by
Don
Bachman.

The West Riverside is a large path along US 550 in southwestern Colorado. It is located in the San Juan Mountains, about 7.7 miles north of Red Mountain Pass. The top of the starting zone is at 11,840 feet. Avalanches can fall 2520 feet to Red Mountain Creek, but large slab avalanches such as this one can climb the 60 feet from the creek to the highway. During the winter of 1931-32 a huge avalanche buried the highway 53 feet X 1000 feet.

Descriptive definition

Snow avalanches are the rapid downslope movement of snow, ice, and associated debris such as rocks and vegetation. "The forces generated by moderate or large avalanches can damage or destroy most manmade structures. The debris from even small avalanches is enough to block a highway or railroad" (Martinelli, 1974, p. 5). Avalanches occur in the mountainous areas of Colorado generally above 8,000 ft. elevation, and most commonly occur from November through April. Avalanche occurrence is directly related to topography, climate, vegetation and aspect* of the area. Much of the information in this report was extracted from "Snow Avalanche Sites – Their Identification and Evaluation" by M. Martinelli, Jr. (1974). Readers with particular interest in avalanches will find that publication quite valuable.

An avalanche site or area is a location with one or more avalanche paths. Avalanche path refers to the specific area where a snow mass moves. A complete path is made up of starting zone(s) at the top where the unstable snow breaks away from the more stable part of the snow cover, runout zone(s) at the bottom where the moving snow and entrained debris stop, and track (s) that run between starting zone, where damage occurs from the turbulent winds that accompany fast-moving powder avalanches. The air blast zone is usually in the vicinity of, but not necessarily continuous with, the lower track or runout zone. In some cases it may even run part way up the slope across the valley from the avalanche path.

Avalanche start most frequently on slopes with average gradients of 30 to 45 degrees. Slopes steeper than 45 degrees usually do not accumulate enough snow to produce very large avalanches in the Rocky Mountain climate. Avalanches may start on slopes of less than 30 degrees if the snow is highly unstable as the result of a prolonged warming trend, heavy snowfall, or unusual wind condition.

These starting zone slope angles are, however, merely the range in which most dangerous avalanches occur; do not assume that slopes outside

this range are safe from avalanches. The average gradient for the entire avalanche path will be more gentle than that of the starting zone. Average gradients of 20 degrees to 35 degrees are common for the tracks of Rocky Mountain avalanches while the slopes in the runout zones are often more gentle and sometimes completely flat, and may even extend up the opposite valley side.

Avalanches are not confined to specific terrain features: they may follow narrow gullies or ravines for all or part of their path; they may occur on broad, uniform slopes or even ridges and spurs. Longitudinal profiles of the paths may be concave, convex, or stepped. On stepped paths, small avalanches will often stop on a bench part way down the tract while larger ones run the full length of the path.

Severity of problem

The severity of avalanche hazard increases when the works of man extend into avalanche areas; therefore, the recognition of the potential aerial extents of avalanches is necessary. This recognition is difficult to achieve when man has not had the opportunity to observe avalanche activity in any particular path over a long enough period of time so that a reasonable assessment of runout potential may be made.

The maximum measured impact pressure of an avalanche is 10 ton/ft (2) while 1 ton/ft (2) is more common. A typical range is from 0.5 to 5.0 ton/ft (2). Air blasts from powder avalanches commonly exert a pressure of 100 lb/ft (2) of force (Martinelli, speech November 8, 1973). Pressures of only 20-50 lb/ft (2) are capable of knocking out most windows and doors. Roads, highways, and railroads are blocked for hours, or sometimes days, every year due to avalanches. Many skiers, other winter sportsmen, and travelers have been injured or killed by avalanche activity.

Lack of recognition of avalanche runout potential has resulted in residential building construction within runout zones in Colorado. When the infrequent, large avalanche event occurs, damage to these buildings will occur unless measures are taken to protect existing structures.

Criteria for Recognition **General**

By far the most reliable way of locating avalanche areas is to study long-term, detailed records of past events when they are available. Such records are available for many localities in Europe, but unfortunately, compilation

is just starting in Colorado.

Usually, data on the location, frequency, or severity of avalanche activity are completely lacking when new areas are considered for highways, winter sports, mining operations, or mountain home sites. Without adequate records of past events, the best alternative is to obtain what data are available, examine the area, map all recognizable paths, estimate the frequency and intensity of the avalanche action, and if possible, start a record of avalanche events.

Active or recently active avalanche paths are most easily identified on air photos or from low-flying airplanes or helicopters. The next best viewpoint is the slope or ridge across the valley from the suspected avalanche area. The entire path should be viewed from such vantage points so that there is less chance of misjudging the size of the path or of overlooking an indistinct or inconspicuous path. Such an overall view makes it possible to spot paths where the aspect of the starting zone and the track are different—an important feature in determining what wind direction causes deposition in the starting zone. Surveys from the valley bottom or lower slopes (the usual road location) are often very misleading. Crooked paths or those with a short, steep pitch in the lower track or runout zone often appear much shorter and smaller than they really are or may not even be recognized as avalanche paths.

Field evidence of avalanche Summer conditions

Avalanche paths in forested areas usually appear as strips straight down the mountain, characterized by a different type or age of the dominant vegetation. These vertical swaths through the trees can be very dramatic when the change is from natural timber to grasses and small herbs. They are less conspicuous but still obvious to most observers when the change is from conifers to aspen or brush. On the other hand, careful scrutiny and often a distant vantage point are needed to spot the change from mature timber to younger trees of the same species. In some cases, avalanches run down slopes with only scattered trees or open park-like stands of trees. These paths are hard to see, and only long and complete records will reveal all of them. Suspected areas should be checked carefully for evidence of avalanche activity. Good indicators of avalanche activity are trees with scars or broken limbs on the uphill side, or trees that lean downhill. Leaning trees deserve a second look, however, to be sure avalanches and not snow or soil creep or a landslide causes them.

An accumulation of wood debris on lower slopes or in the valley may mark an avalanche run-out zone, as might a patch of aspen or young trees at the bottom of a likely avalanche path. Patches of downed trees all aligned in the same direction are a good indication of avalanche activity. Do not discount such patches of downed trees because their tops point uphill. They may mark areas of air-blast, or they may be the result of an avalanche that crossed the valley and ran part way up the opposite slope.

Summer identification of avalanche paths in non-forested areas is difficult and uncertain. Slope steepness, aspect, and surface roughness all offer clues but no proof. Other things being equal, avalanches will be more likely:
On lee slopes than on windward slopes, because of wind loading;
On grass slopes than on brush-covered slopes, because of lower surface roughness;
On shaded northern slopes than on sunny southern slopes, because the snow stays loose and unstable longer; and
On slopes between 30 degrees and 45 degrees than on steeper or gentler slopes because of their ability to accumulate sufficient snow on terrain steep enough to avalanche readily.

Large patches of bare soil surrounded on the sides and above by vegetation, if located on slopes steep enough to avalanche, should be considered possible avalanche starting zones. This lack of vegetation is often due to deep snow accumulation.

Steep rock faces or cliffs that have numerous benches or pockets where snow can accumulate may also be the sources of avalanches in spite of the general statement that very steep slopes usually are not serious avalanche problems.

Many avalanche paths cross both non-forested and forested areas. In the Rocky Mountains, for example, many avalanches start above timberline, their track in the timber. In such cases, the swath through the trees is the most obvious identification feature, but the starting and run-out zones must be given full consideration when establishing size and estimating frequency and intensity of activity.

Winter Conditions

Not all avalanche paths run every year. Many run only once every 5 to 15 years, and others even less frequently. Nor do all avalanches run the full length of their paths every time. Avalanches may stop in the starting zone, track, or run-out zone, depending on the amount and condition of the snow in the

path. Field evidence—usually confined to the starting zone—that an avalanche has occurred includes:

A fracture line or fracture face where the unstable snow broke away as a slab avalanche from the remaining snow cover. This is the most frequently observed and perhaps the most important, single, winter identification feature. The continuity of these fracture lines makes even small ones visible for great distances. New snowfall or drifting snow, however, soon obscures shallow fracture lines and makes even large ones much less distinct.

A change in snow depth and in the texture and features of the snow surface, without a distinct fracture face. All of these features, which mark the start of a loose snow avalanche, are quickly erased by snowfall and drifting snow, and may be missed even by a careful observer. Additional evidence of avalanches—features that may be located in the starting zone, track, or run-out zone, and whose size and location in the path are clues to the size of the avalanche – includes:

Mounds of blocks of snow. Major concentrations usually mark the lower end of the avalanche. Lesser amounts may be scattered higher on the path, at breaks in the slopes, or curved in the track. This is the second most important winter identification feature.

Snow dirtier and denser than the surrounding cover. At times, even after avalanche debris has been covered by fresh snow and all surface indications of avalanche debris are lost, a ski tip or pole or a probe rod can detect the harder, denser avalanche snow beneath. In late spring or summer, these deeper and denser snow deposits often persist after the surrounding cover has melted, and they make excellent identification features. It may be difficult, however, to tell if the debris is from one or more avalanches on the same path.

A clean white swath through gray or dust-covered snow in steep terrain. After snow surfaces have become dust covered or modified by weather during long snow-free periods, the removal of these surface layers by avalanches reveals the clean, unmodified snow beneath. The change in color and texture is noticeable, even if the avalanche left little other evidence.

Accumulations of broken trees, limbs, twigs, leaves, and needles. Entire trees may be uprooted, broken off, or bent over and are usually oriented parallel to the down-slope direction. Large amounts of timber in the debris indicate an avalanche that ran larger than usual or took a different route down the mountain.

Snow, mud, rock, or detached tree limbs plastered against uphill side of standing trees or rocks. These signs often help mark the outer edges of the moving snow. They are most noticeable just after an avalanche has run and are quick to disappear.

Deep grooves in the snow and walls of snow; both usually oriented down the fall line. These indicated avalanches in heavy, wet snow. Grooves and sides of walls are usually smooth and icy. These features are more common in spring avalanches than in winter ones.

“Flag trees” with fresh scars or broken limbs on uphill side of standing trees, and brush with healthy limbs confined to the downhill side. Confusion with wind-damaged trees can be avoided by a complete investigation of the site containing such “flag trees.”

After an avalanche path has been located, it is important to know the size and frequency of avalanches on the path. Long-term observation is the best way to establish avalanche frequency and size. These are, however, available for only a few locations in the United States. The next best thing is to systematically observe the destructive effects of avalanches on the terrain during snow-free conditions. Sometimes, evidence may be found of multiple avalanche events of various sizes and ages through a careful analysis of destruction in the avalanche track and through the distribution of debris in the run-out zone. Additional sources of information may come from “old timers” in the area. Highway maintenance crews, power-line crews, ranchers, trappers, hunters, or fishermen should be quizzed. In more remote areas, ski touring, snow mobiling, or winter mountaineering groups may be a better source of information. Newspaper and other written accounts occasionally help in establishing the data of major events, but are selective toward very large avalanches or those that took lives or did extensive damage.

All incomplete records will be selective in one way or another, and must be used with caution. Highway crews will be most concerned with slides across the road and will seldom pay much attention to those that do not reach the road. Sportsmen will be more apt to see the early avalanches that run during hunting season or those that leave large debris cones that persist in the valley well into fishing season. Such accounts are not definitive in establishing avalanche frequency.

Consequence of Improper Utilization

Avalanches are not a hazard until man’s activities and land uses are affected adversely by the avalanches.

Possible conflicting land uses are recreation, residential, transportation, and mining. Examples of this conflict would include property damage, injury, deaths and excessive maintenance costs.

Deaths

Avalanches can cause deaths whenever people are within the area affected by the avalanche. This area is the entire avalanche path including the air-blast zone. Death can be caused by impact and/or suffocation. In Colorado there have been 43-recorded deaths from avalanches since 1950. This averages about two avalanche fatalities per year for the state (Martinelli, 1974, personal communication).

In the late 1800's and early 1900's the number of fatalities caused by avalanches in Colorado was far greater due to the extensive mining activity in avalanche-prone areas. It has been reported that 119 people died in 1899 alone while it was not uncommon to have dozens killed each year. Now in the 1970's, Colorado is again experiencing an increase of human activity in the high mountain area. H.B. 1041 provides government and citizens with the means to protect property and life from future high losses caused by snow avalanches.

Property damage

Property damage can occur throughout the entire avalanche path. Impact (air or snow) damage ranges from minor to major structural damage to any structure within the path. Vehicles and equipment can be moved great distances and damaged. When deposited, the debris associated with the avalanche might cause damage and be expensive to remove. Roads and bridges may be damaged.

Maintenance

Roads, highways and railroads may become blocked by avalanche snow and debris. In addition to delaying highway and rail travel, it is costly to clear the transportation routes. In a few cases, where avalanches threaten access roads to mountaintop radio and microwave communication sites, emergency repairs and maintenance are delayed. In areas where efforts are underway to control avalanches, the maintenance of avalanche control structures and/or explosive control is costly. In summary, man's activities in avalanche-prone areas can be costly in both money and lives. Improper utilization of avalanche areas includes all uses that generate unacceptable costs in lives or property.

Mitigation Procedures

The location, time, and magnitude of avalanche events are difficult to predict. Because potentially destructive avalanches are relatively common in the

Colorado mountains, anyone planning new facilities and land uses should avoid avalanche-prone sites, or otherwise provide for acceptable safety and economic feasibility of the proposed use.

Avoidance

The safest and probably the most economic mitigation procedure is to avoid building or any type of development involving winter use in avalanche-prone areas. This implies that all avalanche prone areas can be identified and the avoidance is possible.

Non-conflicting use

Non-conflicting land uses of avalanche-prone area include all uses that will not cause loss of life, property, or excessive maintenance. Agriculture and recreational activities that take place during non-avalanche months are desirable non-conflicting uses. Other uses that could be considered are those that involve no permanent unprotected structures in the avalanche path or those that could be moved or closed down during high avalanche-risk periods.

Engineered design and construction for correction of adverse conditions

The two basic methods of avalanche control are: 1) explosive and 2) structural. Explosive techniques have been used for the deliberate release of avalanches for many years. The theory of this technique is to cause many smaller, controlled avalanches and thus avoid large unpredictable destructive avalanches. The principal methods of charge emplacement are: a) hand delivery, in which charges are placed on or in the snow-pack for immediate firing, and b) projectile delivery, in which charges are fired into the snow-pack by guns. Explosive control has been very effective in areas with easy access to avalanche starting zones and ones that can tolerate many small slides without causing damage. Detailed information on current and past snow-pack and avalanche conditions should be available, for this technique to be safe and effective. This method may be unacceptable in areas where easy access to the starting zones is not available, where projectiles must be fired over occupied buildings, where an occasional large avalanche would be especially destructive, or where manpower and facilities are not available to maintain an up-to-date evaluation of snow cover stability. In general, explosive control is probably unacceptable for areas of human occupancy.

Structures for the control of snow avalanches fall into four categories (for details see Martinelli, 1972):

Supporting structures in the starting zone are built in the upper part of the avalanche path to prevent

avalanches from starting, or to retard snow movement before it gains momentum. Some of the first supporting structures were massive earth and stonewalls and terraces intended to interrupt the continuity of the steep slopes and to prevent avalanches. Modern supporting structures in the starting zone may be either rigid or flexible. The rigid ones are made of wood, steel, aluminum, prestressed concrete, or a combination of these materials. Flexible supporting structures called "snow nets" are constructed of steel cables or nylon straps and are held up by steel poles.

Deflecting and retarding structures in the run-out zone are massive structures usually made of earth, rock, or concrete located in or near the avalanche track or run-out zone. The purpose of the structures is to keep the moving snow of an avalanche away from critical locations of structures.

Structures to confine or deflect moving snow should deflect the avalanche as little as possible from the direction of natural flow. Walls built at sharper angles to the flowing snow will often be overrun by fast-moving masses of dry snow.

Retarding structures are usually earth mounds or large concrete structures called breakers or tripods. They should be built on benches or less steep parts of the path where avalanches slow or stop naturally. The additional roughness and cross currents set up by these structures usually stop all but large, dry snow avalanches. Mounds are inexpensive to install and relatively easy to maintain; however, they have been ineffective on slopes steeper than 20 degrees (35%)

Direct protection structures are built immediately adjacent to the object to be protected, or in a few cases, incorporated in the design of the object itself. The aim is to render complete protection regardless of avalanche size, type, or frequency example. Avalanche sheds are merely roofs over a road or railroad that allows avalanches to cross the road without interrupting or threatening traffic. Avalanche sheds are more effective for railroads or narrow roads than for multilane superhighways currently being built.

In actual practice it is common for many different types of structures to be used on a single path. For example, to protect a village with its homes, schools, churches, and roads, from large avalanches, supporting structures, wind baffles, and snow fences may be used in or near the starting zone. These stabilize the upper part of the avalanche path. Mounds, walls, and concrete tripods may be used farther down the mountain to catch any avalanches that start below the supporting

structures. Direct protection structures may also be needed to protect isolated objects such as powerlines or ski-lift towers, mines, or buildings, if any exist in or near the path between the supporting structures and the mounds. In addition, most European avalanche defense systems include reforestation up to the natural tree line.

Obviously, the most desirable and effective protection against avalanches is to locate buildings, roads, and other valuable objects in areas free from avalanches. With ample space and an informed mountain population this is not too difficult. However, as population grows and less desirable sites are considered for development, advanced planning and strictly enforced zoning and construction practices appear the best solutions. In some cases, even these are not adequate to completely eliminate risks for avalanche danger and certain risks must be assumed, especially in the case of roads, powerlines and railroads. These risks can, however, be reduced considerably if appropriate structural controls are employed.

For more information on avalanches please visit the Colorado Avalanche Information Center. From <http://geosurvey.state.co.us/pubs/geohazards/docs/avalanche.asp>.

Drought

drought - an extended period of dry weather, especially one injurious to crops.

DROUGHT

Ironically, droughts are usually associated with "unusually nice weather," for example, very long periods of warm, dry, sunny days.

High temperatures, prolonged high winds, and low relative humidity can aggravate drought conditions.

Twenty Colorado counties declared drought disasters due to loss of winter wheat and hay for cattle in the 1989-1990 season. Losses to the agricultural community were estimated in the millions of dollars.

Loss estimates for the 1976-1977 drought in the Great Plains, Upper Midwest, and Western States were up to \$15 billion. Losses for the 1987-1989 drought in the Central and Eastern states were \$39 billion. In 1998, over \$2 billion in property loss was credited to drought in the United States.

Significant impacts, which may affect Colorado during periods of drought, are those that rely heavily on high water usage. Activities affected include agriculture, tourism, wildfire protection, municipal water usage, commerce, recreation, wildlife preservation, electric power generation, and water quality deterioration.

Droughts can lead to economic losses, such as unemployment, decreased land values, and business losses.

USDA and Small Business Administration disaster declarations include drought. These declarations allow small businesses in certain counties that meet the criteria to apply for low interest Economic Injury Disaster Loans.

(Sources: FEMA 1997; Colorado Office of Emergency Management 2000; www.nws.noaa.gov/om/severe_weather/sum_98.htm)



Many lose their lawn due to drought-like conditions
Photo by Marilyn S. Gally, COEM

Drought News ...

"Hot, dry weather has wilted Colorado's wheat harvest, parched pasture land and drained reservoirs, spurring the growth of desperation, fear and despair among ranchers and farmers."

...
- from "Western Ranchers Fear Crisis," Associated Press Information Services, September 04, 2000

"Just as the Eastern Plains have been scorched by what officials are reluctantly beginning to call a drought, the normally green mountains in Colorado have become parched as well, and residents are beginning to feel the heat. Carbondale officials today are planning to impose watering restrictions, joining a growing list of towns throughout the mountains where rationing is becoming a way of life. Limits on water use are already in place in Kremmling, Basalt, Gypsum, Pinewood Springs and Georgetown."

- from Steve Lipsher, "Heat parches mountains," The Denver Post, August 12, 2000

TYPES OF DROUGHT

Meteorologic: based on degree of dryness; actual precipitation is less than expected average or normal amount.

Hydrologic: based on precipitation shortfall effects on streamflows and reservoir, lake & groundwater levels.

Agricultural: based on soil moisture deficiencies relative to water demands of plant life.

Socioeconomic: occurs when the demand for water is greater than supply due to a weather-related supply shortfall.

Source: FEMA 1997

For complete information on drought in Colorado, refer to The Colorado Drought Mitigation and Response Plan at <http://www.dola.state.co.us/oem/Publications/droughtplan.pdf>

DROUGHT HAZARD IN THE UNITED STATES

The table below lists nine significant droughts in the United States, as listed by the Federal Emergency Management Agency (1997).

NOTABLE DROUGHT EVENTS IN THE UNITED STATES: 1924-1999	
YEARS	REGION
1924-1934	California
1930-1940	Midwest (Dust Bowl)
1942-1956	Southwest
1952-1956	Midcontinent and Southeast
1961-1967	Northeastern States
1976-1977	Great Plains, Upper Midwest, Western States
1980-1981*	Central and Eastern States
1987-1989*	Central and Eastern States
1987-1992	California and Upper Great Plains
1993*	Southeast
1995-1996*	Southern Plains
1998*	Southern States
1999*	Eastern States
2000	Southeastern, Southcentral States
*Refer to BILLION!! Dollar Disaster Events 1980-1999	
Sources: FEMA 1997; www.ncdc.noaa.gov/ol/reports/billionz.html	

According to the National Oceanic and Atmospheric Administration, since 1980 there have been nine drought/heat waves in the United States with losses estimated at over \$1 billion each. Starting with the most recent:

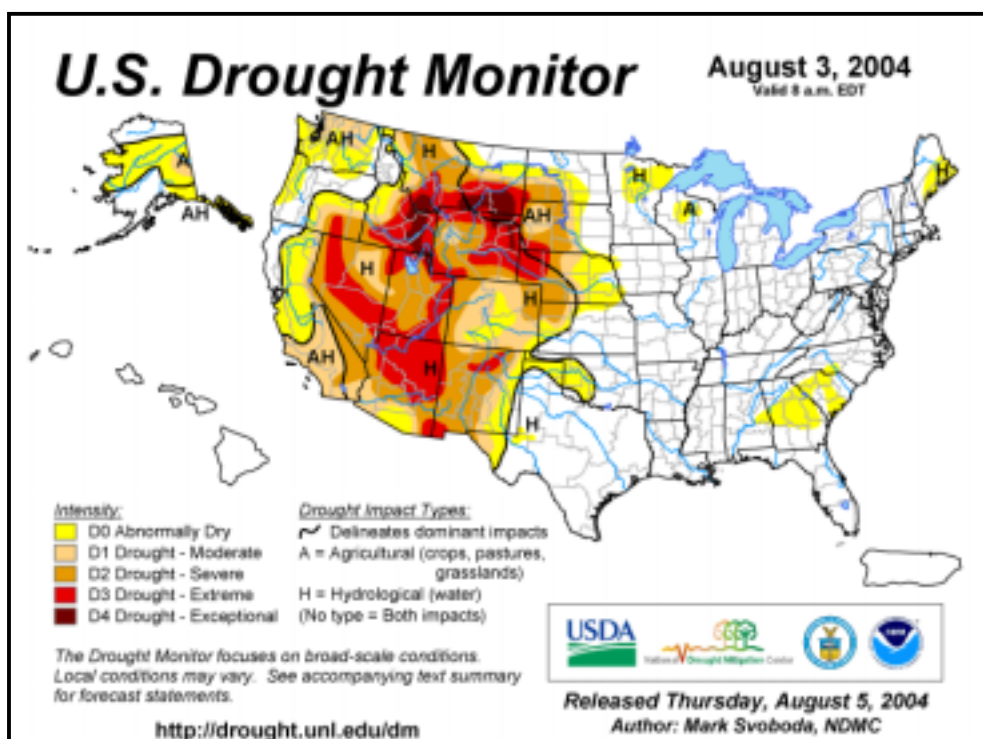
2000 – Southeastern and southcentral states. Estimated losses \$4+ billion and 140 deaths.
1999 – Mainly eastern states. Estimated over \$1 billion in losses and 502 deaths.

1998 – Texas/Oklahoma eastward to Carolinas. Estimated losses \$6 to 9 billion and 200 deaths.
1995-6 – Southern plains. Estimated \$5 billion in losses. No deaths reported.
1993 – Southeast states. Estimated \$1 billion in losses and 16 deaths.
1989 – Northern plains. Estimated \$1 billion in losses. No deaths reported.
1988 – Central and eastern states. Estimated \$40 billion in losses and 5,000 to 10,000 deaths.
1986 – Southeast states. Estimated \$1 to \$1.5 billion in losses and 100 deaths.
1980 – Central and eastern states. Estimated \$20 billion in losses and 10,000 deaths.

The table below demonstrates the amounts of property and crop damage in the United States attributed to drought for three recent years.

SUMMARY OF REPORTED DAMAGE COSTS FOR THE UNITED STATES DUE TO DROUGHT: 1996-2003		
YEAR	PROPERTY DAMAGE (\$ MILLIONS)	CROP DAMAGE (\$ MILLIONS)
1996	135.4	504.1
1997	24.0	253.0
1998	40.0	2,142.0
1999	0.1	1,332.9
2000	0.7	2,438.1
2001	0	1,273.9
2002	0	737.6
2003	645.2	572.5
TOTAL	845.4	9,254.1
Sources: www.nws.noaa.gov/om/severe_weather/		

The map below is from the U.S. Drought Monitor website.



DROUGHT HAZARD IN COLORADO

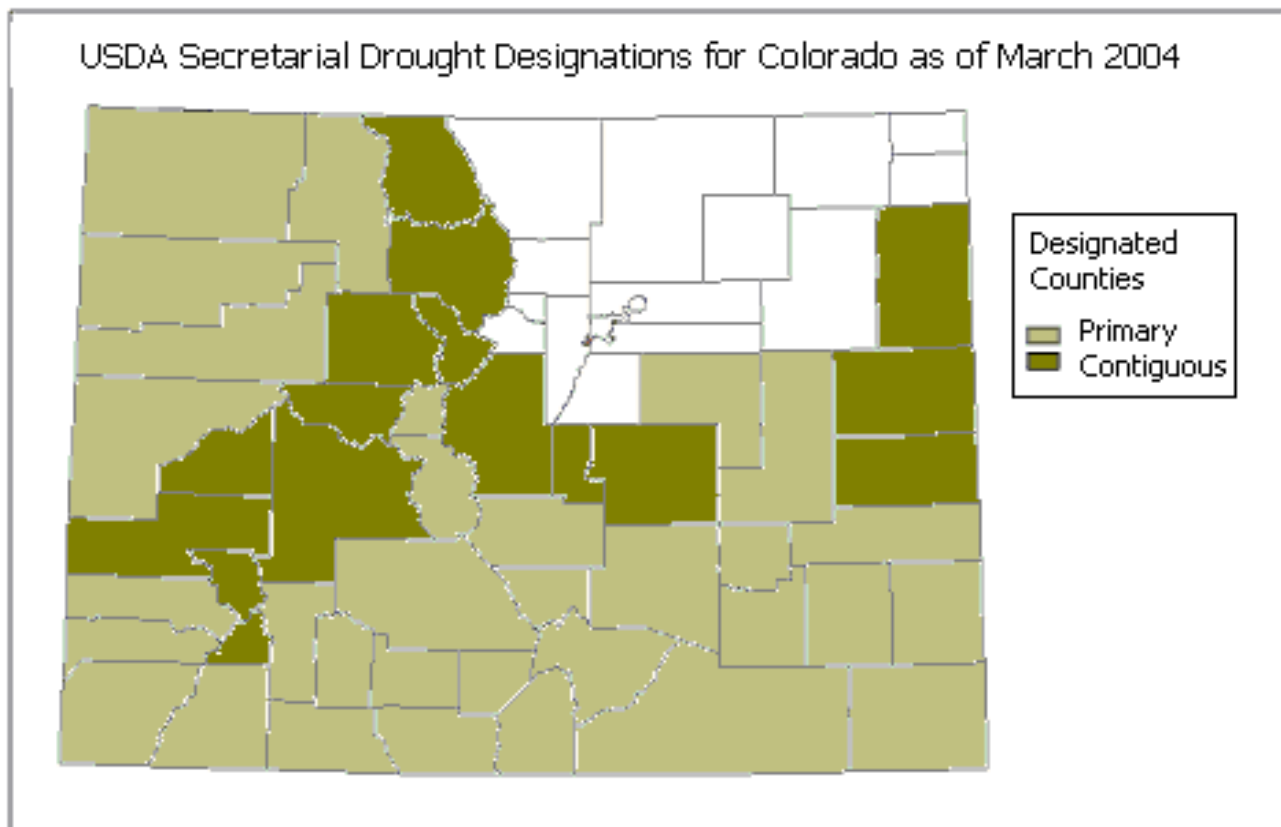
Drought is a natural yet unpredictable occurrence in Colorado. Colorado weather does not provide for a consistent, dependable water supply throughout the year across the state. With Colorado's semiarid and variable climate there will always be concern for water availability within the state" – from The Colorado Drought Mitigation and Response Plan, January 2001.

Several times throughout this century, areas of Colorado have experienced conditions of drought. The most dramatic drought periods occurred in the 1930s and 1950s when many states, Colorado included, were affected for several years at a time. The following table, presented by McKee, Doesken and Kleist (1999), shows five multi-year drought periods experienced in Colorado since 1893.

The map below is adapted from the United States Department of Agriculture website. Primary counties in Colorado declared for drought as of March 2004

HISTORICAL DRY AND WET PERIODS IN COLORADO: 1893-1996			
YEARS	DRY	WET	DURATION
1893-1905	X		12
1905-1931		X	26
1931-1941	X		10
1941-1951		X	10
1951-1957	X		6
1957-1959		X	2
1963-1965	X		2
1965-1975		X	10
1975-1978	X		3
1979-1996		X	17
Sources: McKee, Doesken and Kleist 1999; Colorado Office of Emergency Management 2000			

are Alamosa, Archuleta, Baca, Bent, Chaffee, Conejos, Costilla, Crowley, Custer, Dolores, Elbert, Fremont, Garfield, Hinsdale, Huerfano, Kiowa, La Plata, Lake, Las Animas, Lincoln, Mesa, Mineral, Moffat, Montezuma, Otero, Prowers, Pueblo, Rio Blanco, Rio Grande, Routt, Saguache, and San Miguel. Refer to the Drought Mitigation and Response Plan for more information and explanations on secretarial disaster designations.



<https://disasterhelp.gov/portal/jhtml/usda/usdastatesec.jhtml?community=CO>

For complete information on drought in Colorado, refer to The Colorado Drought Mitigation and Response Plan at <http://www.dola.state.co.us/oem/Publications/droughtplan.pdf>

Earthquake

earthquake - a vibration or movement of a part of the earth's surface, due to the faulting of rocks, to volcanic forces, etc.

QUAKES

Magnitude and intensity are used to describe seismic activity.

Magnitude (M) is a measure of the total energy released. Each earthquake has one magnitude.

Intensity (I) is used to describe the effects of the earthquake at a particular place. Intensity differs throughout the area.

The Northridge Earthquake of 1994 caused **\$20 billion** in damage.

Many earthquakes in Colorado occur naturally; many are caused by human actions. Humans may trigger earthquakes through different types of activities including oil and gas extraction, reservoir impoundment, fluid injection, or mining.

In the 1960s, earthquakes were triggered as a result of activities at the Rocky Mountain Arsenal.

Recent earthquake activity has been triggered by human activities at Rangely Oilfield, Paradox Basin, and Ridgway Reservoir.

Seismic events may lead to landslides, uneven ground settling, flooding, and damage to homes, dams, levees, buildings, power and telephone lines, roads, tunnels, and railways. Broken natural gas lines may cause fires.

Scientists are constantly studying faults in Colorado to determine future earthquake potential. Faults are cracks in the earth's crust along which movement occurs.

Thousands of faults have been mapped in Colorado, but scientists think only about **90** of these were active in the past 1.6 million years.

An earthquake in 1967 caused more than **\$1 million** in damage in the Denver metro area. It may have been caused by injections of liquid waste deep into the earth at the Rocky Mountain Arsenal.

MEASURING EARTHQUAKES

Magnitude and intensity are used to measure earthquakes. A scale commonly used to measure magnitude is the Richter Scale; the Modified Mercalli Scale (MMI) is used for intensity.

MEASURING EARTHQUAKES		
RICHTER SCALE	MODIFIED MERCALLI	DESCRIPTION
2	I	Felt by only a few people. Detected mostly by instruments.
	II	Felt by a few people, especially those on upper floors of buildings. Suspended objects may swing.
3	III	Felt by people indoors. Standing cars may rock slightly. Vibration similar to the passing of a truck.
	IV	Felt indoors by many, felt outdoors by a few; at night, some awakened. Dishes, windows, and doors disturbed. Sensation like a heavy truck striking building. Cars rock.
4	V	Felt by nearly everyone; many awakened. Some dishes, windows broken. Unstable objects overturned.
	VI	Felt by all. Many frightened. Some heavy furniture moved. Some fallen plaster. Damage slight.
5	VII	Many people alarmed. Negligible damage in well built buildings. Considerable damage in poorly built structures.
	VIII	Damage slight in specially designed structures; great in poorly built ones. Heavy furniture overturned. Chimneys and wall may fall.
6	IX	Damage considerable in specially designed buildings; great in substantial buildings. Buildings shift off foundations and crack. Underground pipes broken.
	X	Some well-built wooden structures destroyed. Most masonry and frame structures destroyed. Rails bent. Ground cracked. Landslides on steep slopes.
7	XI	Few, if any, masonry structures remain standing. Rails bent. Bridges destroyed. Broad fissures appear in the ground.
	XII	Damage total. Waves are seen on the ground surface. Objects thrown into the air.

Sources: Colorado Earthquake Project 1999; FEMA 1997

(Sources: www.dnr.state.co.us/geosurvey/pubs/geohazards/docs/sp12.htm; www.dnr.state.co.us/geo/survey/pubs/eqquake/Eqfactsheet.htm; FEMA 1997; The Denver Business Journal 11/26-12/2/99)

EARTHQUAKE HAZARDS IN COLORADO

The following is from "Colorado Earthquake Information" prepared by the Earthquake Subcommittee of the Colorado Natural Hazards Mitigation Council on November 15, 1999.

Introduction - Colorado is comprised of areas with low to moderate potential for damaging earthquakes, based on research by geologists and geophysicists who specialize in seismology. Several 1000 faults have been mapped in Colorado....Thus far, about 90 potentially active faults have been identified, with documented movement within the last 1.6 million years. Because the occurrence of earthquakes is relatively infrequent in Colorado and the historical earthquake record is short (only about 130 years), it is not possible to accurately estimate the timing or location of future dangerous earthquakes in Colorado. Nevertheless, the available seismic hazard information can provide a basis for a reasoned and prudent approach to seismic safety.

Faulting - Sudden movement on faults is responsible for large earthquakes. By studying the geologic characteristics of faults, geoscientists can often determine when the fault last moved and estimate the magnitude of the earthquake that produced the last movement. In some cases, it is possible to evaluate how frequently large earthquakes occurred on a specific fault during the recent geological past.

Geological studies in Colorado indicate that there are about 90 faults that moved during the Quaternary Period (the last 1.6 million years) and should be considered potentially active. The Sangre de Cristo Fault, which lies at the base of the Sangre de Cristo Mountains along the eastern edge of the San Luis Valley, and the Sawatch Fault, which runs along the eastern margin of the Sawatch Range, are two of the most prominent potentially active faults in Colorado. Not all of Colorado's potentially active faults are in the mountains and some cannot be seen at the earth's surface. For example, the Cheraw Fault, which is in the Great Plains in south-east Colorado, appears to have had movement during the recent geologic past. The Derby Fault near Commerce City lies thousands of feet below the earth's surface but has not been recognized at ground level.

Several potentially active faults in Colorado are thought to be capable of causing earthquakes as large as magnitude 6½ to 7¼. In comparison, California has hundreds of hazardous faults, some of which can cause earthquakes of magnitude 8 or larger. The time interval between large earthquakes on faults in Colorado is generally much longer than on faults in California.

Past and Possible Future Earthquakes - More than 400 earthquake tremors of magnitude 2½ or higher have been recorded in Colorado since 1867. More earthquakes of magnitude 2½ to 3 probably occurred during that time, but were not recorded because of the sparse distribution of population and limited instrumental coverage in much of the state. For comparison, more than 20,500 similar-sized events have been recorded in California during the same time period. The largest known earthquake in Colorado occurred on November 7, 1882 and had an estimated magnitude of 6½. The location of this earthquake, which has been the subject of much debate and controversy over the years, appears to be in the northern Front Range west of Fort Collins.

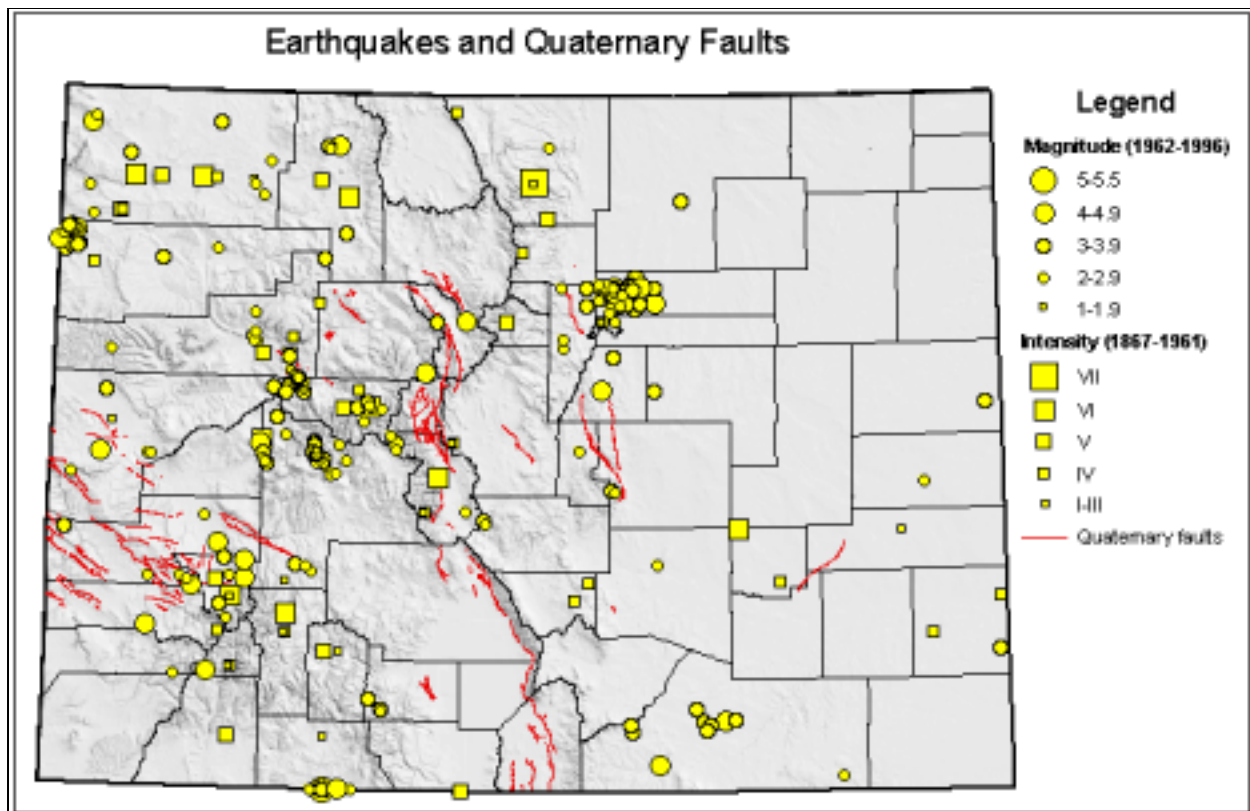
The table below lists notable events in Colorado. Events are considered notable if the magnitude was greater than 5.0 on the Richter Scale or the intensity was greater than V on the Mercalli Scale.

NOTABLE EARTHQUAKE EVENTS IN COLORADO: 1870 THROUGH 2000			
DATE	LOCATION	MAGNITUDE (M) AND INTENSITY (I)	
		M	I
12/04/1870	Pueblo—Ft. Reynolds		VI
10/1871	Lily Park, Moffat Co.		VI
09/17/1880	Aspen		VI
11/07/1882	Northcentral Colorado	6.5*	VII
12/1891	Maybell		VI
11/15/1901	Buena Vista		VI
11/11/1913	Ridgway area		VI
09/09/1944	Montrose-Basalt		VI
08/03/1955	Lake City		VI
10/11/1960	Montrose/Ridgway	5.5	V
01/04/1966	Northeast of Denver	5.0	V
01/23/1966	Southern Colorado border (Dulce, NM)	5.5	VII
08/09/1967	Northeast of Denver	5.3	VII
11/27/1967	Northeast of Denver	5.2	VI
* Estimated, based on historical felt reports. Sources: Colorado Earthquake Project 1999; www.neic.cr.usgs.gov/neis/states/colorado/colorado_history.html ; The Denver Business Journal 11/26-12/2/1999			

Although many of Colorado's earthquakes occurred in mountainous regions of the state, some have been located in the western valley and plateau region or east of the mountains. The most economically damaging earthquake in Colorado's history occurred on August 9, 1967 in the northeast Denver metropolitan area. This magnitude 5.3 earthquake, which was centered near Commerce City, caused more than a million dollars damage in Denver and the northern suburbs. This earthquake is believed to have been induced by the deep injection of liquid waste into a borehole at Rocky Mountain Arsenal. It was followed by an earthquake of magnitude 5.2 three months later in November 1967. Although these events cannot be classified as major earth

quakes, they should not be discounted as insignificant. They occurred within Colorado's Front Range Urban Corridor, an area where nearly 75% of Colorado residents and many critical facilities are located. Since March 1971, well after the initial flurry of seismic activity, 15 earthquakes of approximate magnitude 2½ or larger have occurred in the vicinity of the northern Denver suburbs. Relative to other western states, Colorado's earthquake hazard is higher than Kansas or Oklahoma, but lower than Utah, and certainly much lower than Nevada and California. Even though the seismic hazard in Colorado is low to moderate, it is likely that future damaging earthquakes will occur. It is prudent to expect future earthquakes as large as magnitude 6.5, the largest event of record. Calculations based on the historical earthquake record and geological evidence of recent fault activity suggest that an earthquake of magnitude 6 or greater may be expected somewhere in Colorado every several centuries.

Summary and Conclusions - Based on the historical earthquake record and geologic studies in Colorado, an event of magnitude 6½ to 7¼ could occur somewhere in the state. Scientists are unable to accurately predict when the next major earthquake will occur in Colorado, only that one will occur. The major factor preventing the precise identification of the time or location of the next damaging earthquake is the limited knowledge of potentially active faults. Given Colorado's continuing active economic growth and the accompanying expansion of population and infrastructure, it is prudent to continue the study and analysis of earthquake hazards. Existing knowledge should be used to incorporate appropriate levels of seismic safety in building codes and practices. The continued and expanded use of seismic safety provisions in critical and vulnerable structures and in emergency planning statewide is also recommended. Concurrently, we should expand earthquake monitoring, geological and geophysical research, and mitigation planning.



For more information on earthquakes in Colorado, refer to the Colorado Geological Survey website at <http://geosurvey.state.co.us/>.

HAZUS Summary

Colorado's earthquake hazard and risk has historically been rated lower than most knowledgeable scientists in the state consider justified. As a result, local emergency managers are generally unaware of the size and consequences of an earthquake that could occur in the state. HAZUS 99 gave a probabilistic Annualized Earthquake Loss (AEL) of \$5.8 million which ranked Colorado 30th in the nation.

The Colorado Geological Survey (CGS) recently ran a series of deterministic scenarios for selected faults around the state using HAZUS MH. The earthquake magnitudes used for each fault were the "Maximum Credible Earthquake" taken from the USGS Quaternary Fault and Fold Database or from the USGS National Earthquake Hazard Map. The results demonstrate that the probabilistic AEL value of \$5.8 million does not begin to convey the size of the loss that would occur in the event of a strong earthquake on any of these faults. For example, a magnitude 6.5 earthquake on the Golden fault is forecast to result in a \$22 billion economic loss. Or, consider that a magnitude 6.0 earthquake under the Rocky Mountain Arsenal would result in \$3.9 billion economic loss to Adams County alone; and a loss ratio of 17% that would make recovery difficult.

Much additional work is required to more reasonably characterize Colorado's earthquake risk. CGS believes the following areas should receive the highest priority for additional work and mitigation:

1. Training for emergency responders on the consequences of a strong earthquake.
2. Establishment of a comprehensive seismograph network in Colorado.
3. Development of a landslide susceptibility map for Colorado.
4. Better definition of the attenuation factor (Q) for earthquakes in Colorado.
5. Better characterization of Colorado's known Quaternary faults.
6. Better characterization of Colorado's known Neogene faults.
7. Regional investigation for previously undetected Neogene faults.

Background

In 1960 there were no young faults reported in the literature for Colorado and the dogma being taught in Colorado's institutions of higher education were that the faults in Colorado were all dead, and had been so for 40 million years. Therefore, there was no earthquake hazard in the state.

In 1970, the USGS published a paper that reported eight young faults around the state. By 1980, there were 45. By 1985, there were more than 60. And by 1998, there were more than 90 young faults and

folds identified in the state. Clearly, the more we look, the more we find. But, the looking has been dramatically underfunded.

Colorado's earthquake hazard and risk has historically been rated lower than most knowledgeable scientists in the state consider justified. There are a plethora of reasons for this and the reader is referred to the following publications for a comprehensive review:

Matthews, V. 2003, The Challenges of Evaluating Earthquake Hazard in Colorado, *in* Boyer, D.B, Santi, P.M. Rogers, W.P., Engineering Geology in Colorado-Contributions, Trends, and Case Histories, Association of Engineering Geologists Special Publication No. 15, 22 p.

Matthews, V., 2002, We don't have earthquakes in Colorado do we?: RockTalk, Colorado Geological Survey, v. 5, no.2, 12p. <http://geosurvey.state.co.us/pubs/rocktalk/rtv5n2.pdf>

Matthews, V., 1973, A reappraisal of the seismic-risk classification of Colorado; Mountain Geologist, V. 10, p. 111-115.

HAZUS is driven primarily by the information in the USGS National Earthquake Hazard Map. Resources have not been adequately devoted to understanding Colorado's earthquake hazard. Consequently, the map probably underestimates Colorado's earthquake hazard. Therefore, a probabilistic analysis of Colorado's risk using HAZUS would also be understated.

Some faults in Colorado have received considerable work on hazards. Many of these investigations were conducted by personnel and consultants for the Bureau of Reclamation as part of their dam safety program. With the exception of investigations on the Cheraw and southern Sangre de Cristo faults, the USGS has conducted very few studies of earthquake hazard in Colorado.

The Colorado Geological Survey, with generally inadequate funding and conflicting priorities, has attempted to categorize the extent of young faulting and earthquakes in the state. Several important publications have resulted:

Kirkham, R.M., and Rogers, W.R., 1999, Colorado earthquake information: 1867-1996: Colorado Geological Survey Bulletin 52, CD-ROM.

Kirkham, R.M., and Rogers, W.P., 1981, Earthquake potential in Colorado: Colorado Geological Survey Bulletin 43, 171 p.

Widmann, B.L., Kirkham, R.M., and Rogers, W.P., 1998, Preliminary Quaternary fault and fold map and database of Colorado: Colorado Geological Survey Open- Report 98-8, 331 p.

Deterministic HAZUS Analyses

HAZUS can perform either probabilistic or deterministic analyses. The probabilistic analyses attempt to use statistical probability to predict what the "Annualized Earthquake Losses (AEL) are in each part of the state. These are driven by the USGS National Earthquake Hazard Maps. The deterministic analyses provide "what if" scenarios, e.g. what if a magnitude 6.0 earthquake actually did occur under the Rocky Mountain Arsenal (such a possibility can be found in two different scientific papers). What damage would result, and where would it be located?

HAZUS was recently used to evaluate potential damage from an earthquake on a major feature on Colorado's eastern plains. Because the feature was isolated, intuition suggested that a large earthquake on this feature would not cause significant loss and therefore the expenditure of state resources to investigate the feature was not justified. However, a HAZUS deterministic analysis revealed that a large earthquake could cause more than \$11 billion in economic loss, including \$2.6 billion in the City and County of Denver. Based on this information CGS decided to spend the resources to evaluate the possible earthquake history on the feature.

HAZUS Results

The results of the HAZUS runs are extremely detailed and only the summaries are presented in this document. The full reports are 20 pages and include such things as casualties broken into several categories of severity and calculated at three different times of the day; building damage broken into categories; highway and utility damage; number of people needing shelter; hospitals able to function at 50% capacity one day after the earthquake, seven days after the earthquake, and two weeks after the earthquake; post earthquake fires, and volume of debris to clean up. The following information chart shows the top five losses in several categories: five most damaging faults, 14 highest economic losses, five highest loss ratios for counties, and the five highest calculated potential loss by county.

In the Earthquake Evaluation Report (annex) to this plan are several portrayals of loss. One report shows losses by counties. One table summarizes losses by fault. One map shows the locations and names of the faults analyzed. The other map shows the losses calculated for each fault.

HAZUS Top Fives

Most damaging faults:

1. Rocky Mountain Arsenal
2. Golden
3. Rampart Range
4. Ute Pass
5. Walnut Creek

Total direct economic loss:

1. Rocky Mountain Arsenal M6.5 Counties 150km CEUS – \$24.83 Billion
2. Golden M6.5 Counties 150km CEUS - \$22.08 Billion
3. Rampart Range M7 Counties 150km CEUS - \$18.26 Billion
4. Walnut Creek M6 Counties 150km CEUS - \$13.25 Billion
5. Ute Pass M7 Counties 150km CEUS – \$12.88 Billion
6. Rocky Mountain Arsenal M6 Counties 150km CEUS - \$12.13 Billion
7. Golden M6 Counties 150km CEUS - \$11.41 Billion
8. Rampart Range M7 Counties 150km WUS - \$11.25 Billion
9. Ute Pass M7 Counties 150km WUS - \$9.77 Billion
10. Ute Pass M7 Reverse El Paso County WUS – \$9.30 Billion
11. Rampart Range M7 El Paso County WUS - \$8.15 Billion
12. Golden M6.5 Jefferson County CEUS - \$8.14 Billion
13. Ute Pass M7 El Paso County WUS - \$7.92 Billion
14. Rampart M6.5 Counties 150km CEUS - \$7.04 Billion

Highest loss ratio:

1. Rocky Mountain Arsenal M6.5 Adams County CEUS – 29.7%
2. Ute Pass M7 Reverse El Paso County WUS – 26.8 %
3. South Sawatch M7.25 Chaffee County WUS – 24.1%
4. Rampart M7 El Paso County WUS – 23.5%
5. Ute Pass M7 El Paso County WUS – 22.9%

Counties at greatest risk (high monetary loss, casualties, and loss ratios):

1. El Paso County
2. Jefferson County
3. Denver County
4. Summit County
5. Chaffee County

Expansive Soils

expansive (swelling) soils or rock - "... soils or soft bedrock that increase in volume as they get wet and shrink as they dry out. They are also commonly known as bentonite, expansive, or montmorillinitic soils." (<http://geosurvey.state.co.us/pubs/geohazards/docs/sp12.htm>).

SWELLING SOIL FACTS

Soils that expand have a high proportion of water-absorbing clay particles.

When wet, some expansive soils may expand more than ten percent.

The resulting pressure can be more than 20,000 pounds per square foot on structures such as basement walls and floors. Pressure can be upward, horizontal, or both.

Many times swelling soils present no problem in their natural state, however, exposure to water sources and drying cycles during or after development results in swelling and shrinking. Swelling and shrinking may occur any number of times for a single soil mass.

Most damage occurs to highways, streets, and structures built on expansive soils. Losses can include damage to structures, driveways, roads, sidewalks, basement floors, gas pipelines, and sewer lines.

Damage from expansive soils is estimated to be \$2 billion per year.

Despite knowledge of the problem and technical capability to address it, damages to public facilities in Colorado cost approximately \$16 million annually.

Methods for building in and on swelling soils are well developed and some are very sophisticated. Although there are more up front costs, there is usually no reason to avoid construction provided the appropriate mitigation measures are taken.

(Source: <http://geosurvey.state.co.us/pubs/geohazards/docs/sp12.htm>)

For complete information on swelling soils mitigation, refer to <http://geosurvey.state.co.us/pubs/geohazards/docs/sp12.htm>.

EXPANSIVE SOIL/ROCK HAZARD IN COLORADO

The following is reprinted from the Colorado Geological Survey website at <http://geosurvey.state.co.us/pubs/geohazards/docs/sp12.htm>.

Swelling soils are soils or soft bedrock that increase in volume as they get wet and shrink as they dry out. They are also commonly known as bentonite, expansive, or montmorillinitic soils.



The "roller-coaster road" is the result of uneven swelling and heaving of steeply dipping bedrock layers. Photo by Dave Noe, Colorado Geological Survey

Characteristics

Swelling soils contain a high percentage of certain kinds of clay particles that are capable of absorbing large quantities of water. Soil volume may expand 10 percent or more as the clay becomes wet. The powerful force of expansion is capable of exerting pressures of 20,000 psf or greater on foundations, slabs or other confining structures. Subsurface Colorado swelling soils tend to remain at a constant moisture content in their natural state and are usually relatively dry at the outset of disturbance for construction on them. Exposure to natural or man-caused water sources during or after development results in swelling. In many instances the soils do not regain their original dryness after construction, but remain somewhat moist and expanded due to the changed environment.

Consequences

Swelling soils are one of the nation's most prevalent causes of damage to buildings and construction. Annual losses are estimated in the range of \$2 billion. The losses include severe structural damage, cracked driveways, sidewalks and basement floors, heaving of roads and highway structures, condemnation of buildings, and disruption of pipelines and

sewer lines. The destructive forces may be upward, horizontal, or both.

As seen in the photo below, the bentonite layer heaved approximately three inches within 24 hours after a rainstorm at this construction site. There is also a hump in the fence aligned with the trend of the bentonite layer. Damage is occurring in the subdivision in the background.



A near-vertical bentonite layer in the Upper Cretaceous Pierre Shale in Jefferson County.
Photo by Dave Noe, Colorado Geological Survey

Aggravating Circumstances

Design and construction of structures while unaware of the existence and behavior of swelling soils can worsen a readily manageable situation. Where swelling soils are not recognized, improper building or structure design, faulty construction, inappropriate landscaping and long term maintenance practices unsuited to the specific soil conditions can become a continuing, costly problem. Design problems might include improper foundation loading, improper depth or diameter of drilled pier, insufficient reinforcing steel, and insufficient attention to surface and underground water. Miscalculating the severity of the problem for a particular clay soil can result in damage although some mitigating measures were taken.

Construction problems related to swelling soils include lack of reinforcing steel, insufficient or improperly placed reinforcing steel, mushroom-topped drilled piers, and inadequate void space between soils and grade beams. Allowing clays to dry excessively before pouring concrete and permitting the ponding of water near a foundation during and after construction also are contributing factors in swelling-soil related construction problems. Building without allowance for basement or ground floor movement in known swelling soils areas is a very common source of property damage. Improper

landscaping problems include inadequate management of surface drainage and planting vegetation next to the foundation so irrigation water enters the soil.

Mitigation

Methods for building in and on swelling soils are well developed and some of them are highly sophisticated. Although more costly initially, there is usually no reason to avoid construction *provided the appropriate mitigation measures are taken.*

- Identifying soil problems
- Testing of soils to determine their physical characteristics
- Designing structures to withstand the "worst possible" changing soil conditions as indicated by testing.
- Educating building owners/occupants about the soil situation and its potential significance, especially relative to the role of water.

Land Use

Swelling soils and rock can be a geologic factor that should be considered in the land use. As a soils engineering and foundation design challenge, swelling soils can be managed adequately so as to be secondary to other geologic/construction considerations. Despite this available knowledge and technical capability, selling soils damage in Colorado costs approximately \$16 million annually in public facility damage alone.

Case History

Several structures on the Southern Colorado State University Campus northeast of Pueblo have been damaged because swelling soils were not recognized or compensated for adequately in design, construction and maintenance of buildings, sidewalks, driveways, and water lines. Water percolating into dry soils exposed by construction excavation caused the clays to expand, exerting tremendous upward pressures. Floors, walls, ceilings, sidewalks, water lines, driveways, and other improvements have sustained an estimated \$1.5 million in damages.

Case History

In 1976 at the site of the new maximum security facility for the Colorado State Prison in Fremont County, swelling soils and bedrock were shown on geologic maps. Field investigations and soils tests resulted in a remedial plan by the geologic and soils engineers, architect, builder and others on foundation design, drainage and landscaping. Millions of dollars in potential damages were avoided.

Severity of problem

Swelling soils are a nationwide problem, as shown

by Jones and Holtz (1973): Each year, shrinking or swelling inflict at least \$2.3 billion in damages to houses, buildings, roads, and pipelines – more than twice the damage from floods, hurricanes, tornadoes, and earthquakes...Over 250,000 new homes are built on expansive soils each year. 60 percent will experience only minor damage during their useful lives, but 10 percent will experience significant damage-some beyond repair...one person in 10 is affected by floods; but one in five by expansive soils.

Swelling is generally caused by expansion due to wetting of certain clay minerals in dry soils. Therefore, arid or semi-arid areas such as Colorado with seasonal changes of soil moisture experience a much higher frequency of swelling problems than eastern states that have higher rainfall and more constant soil moisture.

Rocks containing swelling clay are generally softer and less resistant to weathering and erosion than other rocks and therefore, more often occur along the sides of mountain valleys and on the plains than in the mountains. Because the population of Colorado is also concentrated in mountain valleys and on the plains, most of the homes, schools, public and commercial buildings, and roads in the state are located in areas of potentially swelling clay. Swelling clays are, therefore, one of the most significant, widespread, costly, and least publicized geologic hazards in Colorado.

Criteria for Recognition

Although several visual methods for identification of potentially swelling clays exist, only a competent, professional soil engineer and engineering geologist should be relied upon to identify this potential hazard. Some warning signs for swell might include: a) soft, puff, "popcorn" appearance of the surface soil when dry; b) surface soil that is very sticky when wet; c) open cracks (desiccation polygons) in dry surface soils; d) lack of vegetation due to heavy clay soils; e) soils that are very plastic and weak when wet but are "rock-hard" when dry.

Engineering soil tests include index tests and design tests. Rapid, simple index tests are used to determine whether more complex design tests are necessary. Some index properties that may aid in the identification of probable areas of swelling clay include Atterberg limits, plasticity index, grain size determination, activity ratio, dry unit weight, and moisture content (Asphalt Institute, 1964). The primary design tests for swelling soils are the consolidation swell* test for buildings, and the California Bearing Ratio* swell test for roads (Asphalt Institute, 1964).

Consequences of Improper Utilization

Damage from swelling clays can affect, to some extent, virtually every type of structure in Colorado. Some structures, such as downtown Denver's skyscrapers, generally have well engineered foundations that are too heavily loaded for swelling damage to occur. At the opposite extreme are public schools and single family homes, which are generally constructed on a minimal budget and which may have under-designed lightly loaded foundations that are particularly subject to damage from soil movements. Homeowners and public agencies that assume they cannot afford more costly foundations and floor systems often incur the largest percentage of damage and costly repairs from swelling soil.

In 1970, the state of Colorado spent nearly \$1/2 million to repair cracked walls, floors, ceilings, and windows caused by swelling-clay damage at a state institution near Denver. In 1972, a state college library in southern Colorado required \$170,000 to repair swelling-clay damage. A 6-yr-old, \$2 million building on the same campus was closed pending repairs to structural components pulled apart by swelling clay. A college building in western Colorado and a National Guard armory near Denver are among the other state buildings severely damaged by swelling clays. These examples of damage to public buildings do not include the hundreds of thousands of dollars spent for repairs by local school districts. One school district near Denver is attempting to circumvent these expensive repairs by spending an additional \$42,000 per school on structural floors. No figures are available for the total damage to homes in Colorado from swelling clays. However, several examples are known where the cost of repairs exceeded the value of the house. Cracked and heaved sidewalks, patios, driveways, and garage and basement floor slabs are very common indicators of swelling clay throughout Colorado.

Highways in some areas of Colorado have required frequent and very expensive reconstruction or maintenance due to damage from swelling clay. As much as one foot of uplift from swelling clay forced the repair of two concrete lanes of interstate highway in eastern Colorado only six months after completion of paving. In the same area, additional right-of-way had to be purchased, and the highway design had to be revised to eliminate cuts and fills in order to prevent similar problems with the two remaining lanes.

Mitigation Procedures

Complete avoidance or non-conflicting use:
In Colorado, swelling clays are so common in urban areas that complete avoidance is generally not

feasible. However, all should recognize the widespread distribution of swelling soils, and precautions must be taken to require engineered foundation and floor systems designs and to provide detailed maintenance instructions to owners in affected areas that are to be developed.

Engineered design for correction of adverse conditions: Combinations of four methods – engineered foundation design, well planned site drainage, landscaping to enhance drainage, and careful interior construction details, may minimize swelling clay damage.

Foundation design. In areas of relatively low swell potential, spread footings are commonly used. For slightly high swell pressures, extended bearing walls or pads may be used. In areas containing moderate to highly swelling clay, drilled pier and grade beam foundations are used. The weight of the building is transmitted through bearing walls to horizontal grade beams. These beams rest on cylindrical, reinforced concrete piers that concentrate the weight on a very small area below the zone* of seasonal moisture change. The foundation is thereby founded upon soil that because its moisture content remains constant throughout the year, should not experience a volume change.

With each of these special foundation designs, floating slabs are commonly used for all on-grade floors. These interior concrete floor slabs are completely isolated by joints or void spaces from all structural components. Complete isolation from bearing walls, columns, non-bearing interior partitions, stairs, and utilities allows the slab to move freely without damaging the structural integrity of the building. In the Denver area, swelling soil below the level of the proposed floor slab is sometimes excavated to a depth of several feet and replaced by various kinds of engineered backfill.

Overexcavation where expansive soils and/or bedrock are removed below the foundation and replaced with compacted fill. The mixing of the soil, the addition of moisture to the fill materials and compaction of the fill material reduces the swell potential of the soils. The mixing of the soil also reduces the chances of differential swell within the fill.

Drainage. The Federal Housing Administration recommends slopes of no less than 6 in. of vertical fall in 10 ft (12 in. in 10 ft is safer) around all buildings for drainage water into drainage swales, streets, or storm sewers. *Water must not be allowed to stand near foundations* in areas of swelling clay due to the potential for wetting foundation soils. All downspouts and splash blocks should be placed so that roof runoff will be carried at least 4 ft from the building. In areas of heavy lawn irrigation, peripheral drains have proven effective in preventing the formation of perched water tables and the resulting downward seepage of the surface water. The clay-tile or perforated plastic peripheral drains completely surround the building just below the level of the floor. The drain is and covered with washed gravel and a geotextile. The drain is normally connected to a main collection line located beneath the sanitary sewer, a sump or a daylight or gravity discharge point.

Landscaping. Proper foundation design and construction will not solve all swelling-clay problems. The owner of a structure is responsible for maintaining proper drainage by careful landscaping. Backfill around foundations is often not properly compacted. Therefore, additional soil may be required on the slope around the structure in order to compensate or settlement of the backfill. This prevents “ponding” and percolation of water around the foundation. Grass, shrubs, and sprinkler systems should be kept a minimum of 5 ft from the foundation. Trees should be planted no nearer than 15 ft from a building. The most critical aspect of landscaping in swelling clay areas is *not to flatten a properly designed slope*.

Interior finishing. One of the most costly mistakes a homeowner or careless contractor can make is to defeat the design purpose of a floating floor slab. A floating garage or basement floor slab is designed to move freely. Therefore, any furring, paneling, dry wall, or interior partitions added to a basement or garage must maintain this freedom of vertical movement. Any added walls or wall coverings should be suspended from the existing walls or ceiling, and should not be attached to the floor slab. A minimum void space of 3 in. should then be provided just above the floor slab. This void space may be covered with flexible molding, or inflexible molding attached to the floor rather than the wall. Although these recommendations provide for 3 in. of upward swell of the soil beneath the floor slab, more void space may be necessary in areas of highly swelling clay.

Fire

wildfire - "an open fire which spreads unconstrained through the environment. If not quickly controlled, the result can be a firestorm, often termed a 'conflagration,' which destroys large amounts of property and threatens lives." (Colorado State Forest Service 1995)

FIRE FACTS

Topography, fuel, and weather are the three main factors that affect wildfires.

There are four categories of wildfires:

Wildland fire - fuel is mainly natural vegetation;

Interface or intermix fire - urban/wildland fires, both vegetation and manmade fuel;

Firestorm - very intense event, suppression very difficult; and

Prescribed/prescribed natural fire - fire set or natural fire allowed to burn.



One of many fires in Colorado in 2000
Photo provided by the CDEM

From 1988 to 1997, an average of **116,573** wildland fires burned **each year**. Of those, human actions caused an average of 102,694 fires and burned an average of 1,942,106 acres. Lightning caused 13,879 fires and burned an average of 2,110,810 acres.

According to the National Interagency Fire Center, fire suppression costs for Bureau of Land Management, Bureau of Indian Affairs, Fish and Wildlife Service, National Park Service, and U.S. Forest Service for the six years from 1994 to 1999 were close to **\$3 billion**.

Over the past 25 years, at least eight presidential disaster declarations were for wildfires and over 100 wildfires have qualified for federal fire suppression/management assistance grants.

From January 1, 2000 to September 27, 2000, over **6,800,000** acres burned in the United States from wildfires. Colorado had **126,952** acres burn.

For complete information on wildfire, refer to the Colorado Wildfire Mitigation Plan located online at <http://www.colostate.edu/Depts/CSFS/govpage.html>.

The Colorado Division of Fire Safety estimates that over **\$36 million** in property losses occurred from wildland fires from 1990 to 1994.

Other hazards can produce wildfires or aggravate conditions. For example, high winds may down powerlines, earthquakes may crack gas lines, and volcanoes, lightning, and floods can cause fires. Areas experiencing extreme drought conditions are particularly vulnerable to lightning strikes.

Wildfires destroy vegetation, which can contribute to mudslides, landslides and floods. Large fires can also create very strong winds.

In 1991, **4,465** civilian deaths, **21,850** injuries, and over **\$8 billion** in damages were attributed to structural fires.

Lightning can cause structural fires as well as wildfires. In 1997 in Denver, a warehouse fire caused by lightning resulted in a **\$70 million loss**.

One of the most noted urban fires is the Great Chicago Fire of 1871. Attributed to this fire were 1,152 deaths, 17,450 burned buildings, and damage estimated at \$168 million.

Due to the risk of fire from lightning strikes, it is very dangerous to store flammable liquids in rooftop storage tanks.

Winds can aggravate fire conditions by spreading embers and sparks. Earthquakes and debris floating in floodwaters can rupture natural gas lines, causing fires.

Some of the factors used in risk assessment of buildings for lightning events may include structure type, construction type, location, topography, occupancy and contents.

(Sources: www.nifc.gov/fireinfo/nfnmap.html; www.nifc.gov/stats/wildlandfirestats.html; FEMA 1997)



WILDFIRE HAZARD IN THE UNITED STATES

The table to the top right is a summary of the total fires and acres burned in the U.S. from 1990 through 2003. The figures are based on end-of-year reports compiled by wildland fire agencies (Bureau of Land Management (BLM), Bureau of Indian Affairs (BIA), National Park Service (NPS), U.S. Fish and Wildlife Service (USFWS), USDA Forest Service (USFS) and state lands) after each fire season. Complete information is found at <http://www.nifc.gov/stats/wildlandfirestats.html>. Total fires and acres burned data goes back to 1960.

FIRE SUPPRESSION COSTS FOR FEDERAL AGENCIES (BLM, BIA, USFWS, NPS, USFS) FROM 1994-2003	
YEAR	FIVE AGENCY TOTAL
2003	1,326,138,000
2002	1,661,314,000
2001	917,800,000
2000	1,362,367,000
1999	523,468,000
1998	328,526,000
1997	256,000,000
1996	679,167,600
1995	340,050,000
1994	845,262,000
TOTAL	6,913,954,600

www.nifc.gov/stats/wildlandfirestats.html

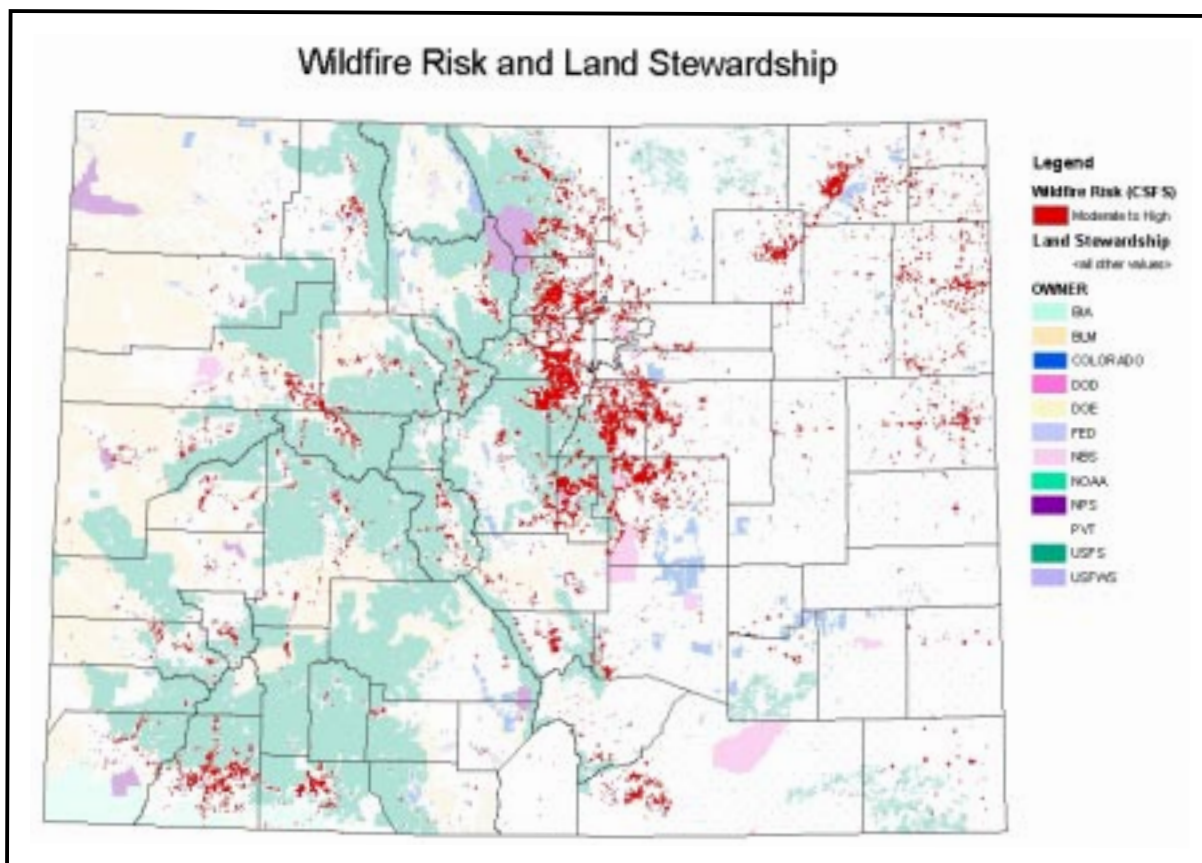
TOTAL FIRES AND ACRES BURNED IN THE U.S. FROM 1990-2003		
YEAR	FIRES	ACRES
2003	85,943	4,918,088
2002	88,458	6,937,584
2001	84,079	3,555,138
2000	122,827	8,422,237
1999	93,702	5,661,976
1998	81,043	2,329,709
1997	89,517	3,672,616
1996	115,025	6,701,390
1995	130,019	2,315,730
1994	114,049	4,724,014
1993	97,031	2,310,420
1992	103,830	2,457,665
1991	116,953	2,237,714
1990	122,763	5,452,874

www.nifc.gov/stats/wildlandfirestats.html

The table to the left shows the total suppression costs by year for the five federal land management agencies. Three times during the ten-year period, the suppression costs surpassed \$1 billion. Costs were just under \$7 billion for the ten years.

WILDFIRE HAZARD IN COLORADO

The map below was developed by the Colorado Office of Emergency Management. The layers of moderate to high wildfire risk, as developed by the State Forest Service, and land stewardship are displayed. More land stewardship information is provided in the Colorado Information Section.



The table below lists notable fire events in Colorado.

NOTABLE FIRE EVENTS IN COLORADO		
YEAR	LOCATION/NAME	COSTS/LOSSES
1937	Roosevelt NF	1 death
1976	Grand Junction	4 deaths
1985	Columbia	1 death
1986	Montrose	4 deaths
1988	Lefthand Canyon, Boulder Co.	2,500 acres
1989	Black Tiger, Boulder Co.	\$10,000,000, 44 structures, 2,100 acres
1989	Panorama, Garfield & Eagle Counties	Unknown
1990	Olde Stage, Boulder Co.	10 structures, 2,100 acres
1991	Routt NF	1 death
1992	Glenwood Springs	1 death
1994	Hourglass (Pingree Park)	13 structures, \$2,200,000
1994	Wake, Delta Co.	\$2,675,000, 3 structures, 4,000 acres
1994	South Canyon, Garfield Co.	14 deaths, 2,340 acres
1994	Roxborough, Jefferson Co.	100 acres
1996	Buffalo Creek, Jefferson Co.	\$3,835,000, 10 structures, 12,000 acres
1999	Monument	9 structures, 100 acres
2000	Eldorado, Boulder Co.	\$2,000,000
2000	Bobcat, Larimer Co.	22 structures, 10,600 acres
2000	Hi Meadow, Jefferson Co.	51 structures, 10,927 acres
2000	Pony Fire	4 structures, 5,240 acres
2000	Eldorado Fire-Walker Ranch	1,061 acres
2001	Larkspur	1 death
2001	Armageddon Fire-Carter Lake	1,216 acres
2002	Snaking Fire	2,312 acres, 2 structures
2002	Cuerno Verde Fire	388 acres, 4 structures, 2 injuries
2002	Black Mountain Fire	200 acres, 1 injury
2002	Schoonover Fire	3,862 acres, 12 structures, 1 bridge, 2 injuries
2002	Iron Mountain Fire	4,440 acres, 200+ structures, 3 injuries
2002	Spring and James John/Fisher Fires (Trinidad Complex)	17,295 acres, 6 injuries
2002	Ute Pass Fire	
2002	Coal Seam Fire	12,209 acres, 61+ structures & improvements
2002	Hayman Fire	137,760 acres, 6 deaths, 16 injuries, 600 structures
2002	Dierich Creek/Long Canyon Fires (Miracle Complex)	3,951 acres, 1 injury
2002	Missionary Ridge Fire	70,485 acres, 12+ structures, 52 injuries
2002	Million Fire	9,346 acres, 11 structures
2002	Wiley Ridge Fire	1,084.5 acres
2002	Valley Fire	400 acres, a few homes
2002	Burn Canyon Fire	31,300 acres, 9 injuries
2002	Big Elk Fire	4,100 acres, 1 airtanker, 3 deaths
2002	Panorama Fire	
2003	Cherokee Fire	
Sources: Teie & Weatherford 2000, Wildfire Hazard Mitigation Plan 2002		

The 2003 Wildfire Season Summary

According to the "National Report of Wildland Fires and Acres Burned by State," in 2003 Colorado had a total of 2,180 fires reported and 53,412 acres burned. One hundred twenty-two fires were pre-scription burns for a total of 22,238 acres. Fires are categorized by county, state, and federal agencies, including BIA, BLM, DDQ, FWS, NPS and USFS.

The 2002 Wildfire Season Summary

The 2002 Colorado Wildfire season was the worst on record. It began in April and continued until early Fall with periods when multiple large fires were burning simultaneously. Details of the season are highlighted below:

Four thousand six hundred and twelve fires burned 619,030 acres during the 2002 season. The ten-year average is 3,119 fires burning 70,000 acres.

Twenty-two large fires (of which 17 qualified for FEMA assistance) became state responsibility fires with an estimated cost to the state of over \$24 million dollars.

Thirteen Type I and II Incident Management teams were utilized.

One hundred forty-two subdivisions were evacuated, displacing 81,435 people.

384 homes were lost and an additional 624 other structures were destroyed.

Sixteen-thousand five-hundred firefighters fought Colorado's 2002 incidents. Tragically, nine firefighters were killed. One air tanker and one helicopter were lost killing three people.

Suppression costs for 2002 expected to exceed \$152 million.

While these numbers are dramatic, they are not surprising. A century of aggressive fire suppression, combined with cycles of drought and changing land management practices, has left many of Colorado's forests unnaturally dense and ready to burn. At the same time, the state's record setting growth has driven nearly a million people into the forested foothills of the Front Range and along the West Slope and central mountains – the same landscapes that are at highest risk for large-scale fire. This movement of urban and suburban residents into the wildland-urban interface (WUI) significantly increases the values-at-risk from wildland fire – the most critical of these being human life.

The 2001 Wildfire Season Summary

In October, 2001, a fire management assistance grant was awarded to the State of Colorado to support fire-fighting activities associated with containing the Armageddon Fire. The fire began on October 31, 2001. The fire was in the foothills along the Front Range in Colorado.

The 2001 fire season in Colorado was not as spectacular as the 2000 fire season. At 4022, the number of fires that started was above the 2000 year total of 3698 fires but the acreage burned (72,210) was significantly less than the 249,976 acres burned in 2000. The Armageddon Fire was the only fire that met the criteria for a Fire Management Assistance Grant.

The Armageddon Fire began on October 31, 2001. The fire was located in Larimer County and threatened approximately 100 homes in the Carter Lake area. The fire was human-caused fire. The fire originated on private land and expanded quickly, fanned by high winds. Initial response to the fire focused on evacuation and structure protection. The complexity of the fire led to the order for an Interagency Type 2 Incident Management Team. The fire was returned to local management on November 3, 2001. The final size of the fire was calculated at 1216 acres, all in private ownership. Like most large fires, the fire was weather driven-wind controlled. The biggest concerns were high winds, light flashy fuels, narrow roads with congested urban traffic and a private dump with unknown material in it.

A total of 1216 acres were burned. No dwellings were destroyed and no lives were lost or serious injuries reported from any of the fires.

The 2000 Wildfire Season Summary

In June 2000, two fire assistance grants were awarded to the State of Colorado to support fire-fighting activities associated with containing the Bobcat Gulch and Hi Meadow Fires. Both fires began on June 12th 2000. A third fire assistance grant was awarded to the State of Colorado for the Eldorado/Walker Ranch (Eldorado) Fire that began on September 15th, 2000. All fires were in the foothills along the Front Range in Colorado.

The fire season began early in 2000. The Hi Meadow, Bobcat Gulch, and Eldorado were the three fires that resulted in Fire Suppression Assistance Grants. The Bobcat Gulch fire started on the morning of June 12th 2000. The cause of the fire was human error – an escaped campfire. The fire was located in Larimer County approximately one mile north of the Town of Drake with the affected

acreage in Township 6 North and Ranges 70 and 71 West. The Bobcat Gulch fire burned in the Arapahoe-Roosevelt National Forest. Fuels included brush, ponderosa pine, spruce-fir, and lodge pole pine at higher elevations of the fire. The fire impacted the Cedar Park Subdivision where a total of 60 homes were evacuated. The fire threatened structures in an area from Eden Valley to Buckhorn Creek. The fire consumed 10,599 acres of grass, brush, and timber and destroyed 18 homes within the wildland interface out of a total of 25 sites where property was reported as destroyed or damaged. An estimated 1500 to 2000 residences were within easy reach.

The Hi Meadow fire also started on June 12th. The Hi Meadow fire began in Jefferson and Park Counties. The location of the fire was about 35 miles southwest of Denver. It was caused by human activity. The Hi Meadow fire affected federal, state, and private lands and resulted in the evacuation of approximately 600 residents from two towns (Pine and Buffalo Creek), and 19 subdivisions in the area. The Hi Meadow Fire had 3000 structures in the interface that could have been affected. The control date for the Hi Meadow fire was on June 25th. A total of 10,800 acres were burned: 5,623 acres on federal land and 5,177 acres were on state or private land. A total of 10,592 acres were in Jefferson County and 208 acres in Park County. A total of 51 residences, six outbuildings, and one commercial building were lost.

The Eldorado fire began on September 15. The fire was located approximately seven miles southwest of the City of Boulder and is suspected to be human caused. It started on county administered open space called Walker Ranch Park. It affected County land, Denver Water Board land, and private lands. The fire burned in mixed Douglas fir and ponderosa pine with interspersed open grasslands and shrubs. The blaze consumed over a thousand acres (1,061). It posed a threat to residents in the Pine Notch, Lake Shores and Juniper Heights subdivisions and forced the evacuation of over 200 residents from 125 homes. No residences or other structures were lost. Besides the homes, utilities, park facilities, historic structures, Denver Water Board lands with significant watersheds, and riparian and fisheries resources were also at risk.

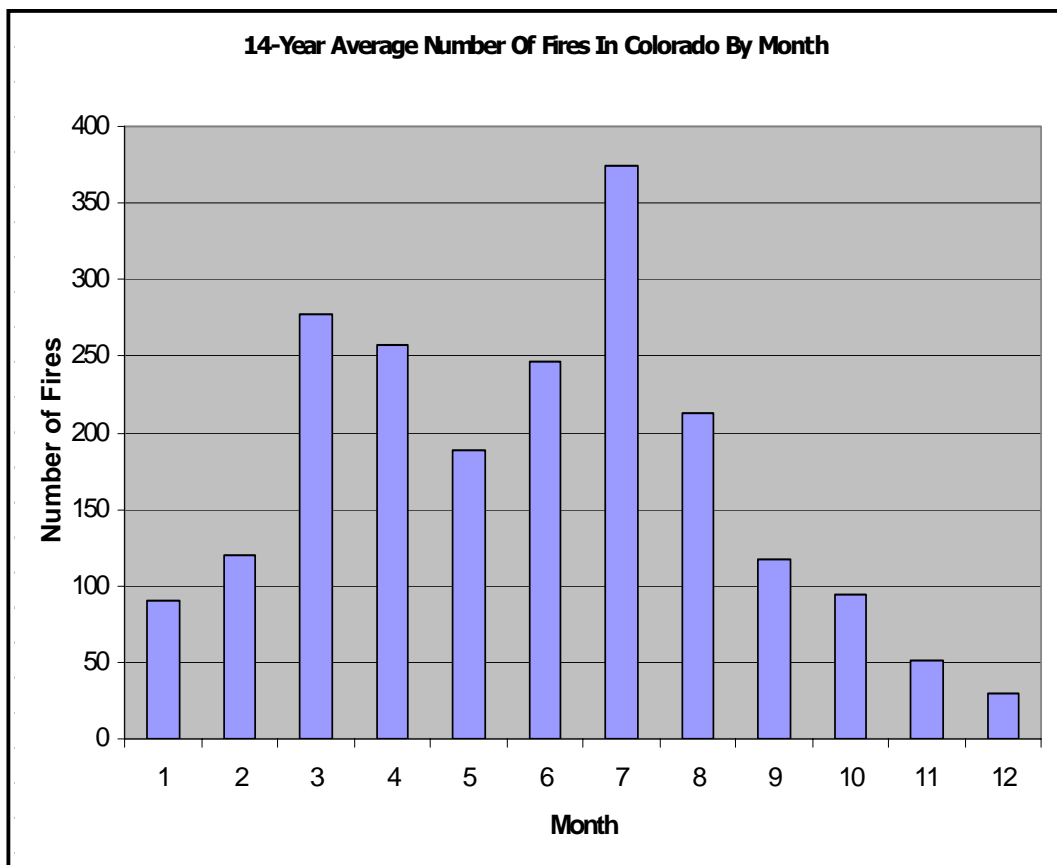
Like most large fires, the three fires were weather driven-wind control. One of the biggest problems was a high fuel load. The areas' steep terrain and high altitude made firefighting difficult. The State also dealt with a limited number of resources.

The tables on this page show statistics provided by the Colorado State Forest Service for a 14-year period from 1990 through 2003. In that period, there were a total of 28,820 reported fires on state and private lands. Over 600,000 acres burned.

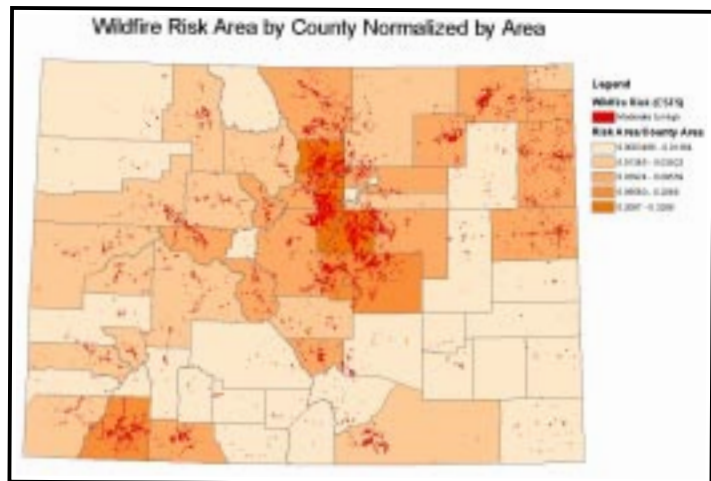
The second table and chart at the bottom of the page demonstrate that fires occur every month. The most fires occurred in July seven of the 14 years, followed by March, April, June, August, and May. The 14 year average number of fires per year is 2,059. Over the years, most acreage has burned in May, June, July, and August. Conditions such as drought and beetle kill add to fire risk.

FIRES IN COLORADO ON STATE AND PRIVATE LANDS BY YEAR: 1990-2003		
YEAR	NUMBER	ACRES
2003	2,150	16,104
2002	3,335	244,239
2001	2,953	45,816
2000	2,043	76,288
1999	2,161	35,261
1998	1,349	10,282
1997	1,605	16,703
1996	2,499	49,498
1995	2,368	34,293
1994	3,190	52,184
1993	1,267	3,526
1992	1,020	4,135
1991	1,406	6,787
1990	1,474	9,825
Totals	28,820	604,941
Colorado State Forest Service 2004		

COLORADO STATE AND PRIVATE LAND FIRES: 14-YEAR AVERAGES BY MONTH FROM 1990-2003												
MONTH	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
14-yr average number per month	90	120	278	257	189	246	374	213	117	94	51	30
14 year average acres per month	801	1,609	2,874	2,711	4,853	14,164	5,913	6,420	1,809	1,189	826	42
Colorado State Forest Service 2004												



Two major risk assessment have been completed in the past. The first was completed by the Colorado State Forest Service and the Colorado Office of Emergency Management in March of 1999 known as the Midlevel Assessment. The table below represents data from that model. The wildfire risk is shown in acres and as the percent of the county with a moderate to high hazard. The layer was combined with the moderate to high hazard risk layer to create the map to the right.



COLORADO COUNTIES BY PERCENT OF ACRES AT RISK FOR WILDFIRE: 1999*							
% AREA AT RISK	COUNTY	MODERATE TO HIGH HAZARD (ACRES)	TOTAL ACRES	% AREA AT RISK	COUNTY	MODERATE TO HIGH HAZARD (ACRES)	TOTAL ACRES
0.06	Adams	497.78	768,098.50		Kit Carson		
2.65	Alamosa	12,233.72	462,496.20	9.33	Lake	22,870.38	245,001.80
1.12	Arapahoe	5,748.71	514,107.30	26.46	La Plata	287,983.31	1,088,385.00
26.36	Archuleta	228,558.66	867,207.00	21.91	Larimer	368,957.77	1,684,129.00
	Baca			7.09	Las Animas	216,392.35	3,053,720.00
	Bent				Lincoln		
19.80	Boulder	95,168.25	480,686.40		Logan		
	Broomfield			25.81	Mesa	552,686.56	2,141,740.00
19.80	Chaffee	128,559.50	649,452.80	5.49	Mineral	30,831.46	561,889.90
	Cheyenne			3.80	Moffat	115,639.59	3,042,580.00
29.21	Clear Creek	73,998.63	253,372.60	17.68	Montezuma	230,435.72	1,303,012.00
2.95	Conejos	24,337.81	826,095.90	24.45	Montrose	351,531.89	1,437,765.00
5.99	Costilla	47,137.33	787,009.30		Morgan		
	Crowley				Otero		
19.93	Custer	94,314.40	473,309.80	23.38	Ouray	81,149.07	347,072.30
21.15	Delta	155,555.62	735,609.50	14.47	Park	204,649.50	1,414,525.00
0.01	Denver	8.64	99,617.14		Phillips		
6.60	Dolores	45,495.34	689,285.80	21.01	Pitkin	130,464.21	621,026.90
35.97	Douglas	193,724.18	538,527.30		Prowers		
29.32	Eagle	319,184.56	1,088,545.00	3.07	Pueblo	47,180.53	1,534,410.00
0.80	Elbert	9,411.22	1,182,788.00	9.04	Rio Blanco	186,769.06	2,065,924.00
18.36	El Paso	250,229.55	1,362,591.00	6.03	Rio Grande	35,238.91	584,600.10
33.78	Fremont	331,266.29	980,558.00	17.55	Routt	265,245.90	1,511,680.00
39.93	Garfield	755,612.73	1,892,209.00	14.31	Saguache	290,135.10	2,027,853.00
20.50	Gilpin	19,728.13	96,212.98	0.34	San Juan	841.74	248,753.50
11.47	Grand	137,260.33	1,196,335.00	20.99	San Miguel	173,351.36	826,057.50
22.32	Gunnison	465,280.69	2,084,727.00		Sedgwick		
5.59	Hinsdale	40,199.48	719,278.60	13.10	Summit	51,892.21	396,124.60
15.09	Huerfano	153,756.32	1,019,181.00	32.06	Teller	114,669.95	357,724.60
2.29	Jackson	23,784.72	1,036,872.00		Washington		
56.84	Jefferson	282,540.56	497,076.60	0.05	Weld	1,403.47	2,570,639.00
	Kiowa				Yuma		

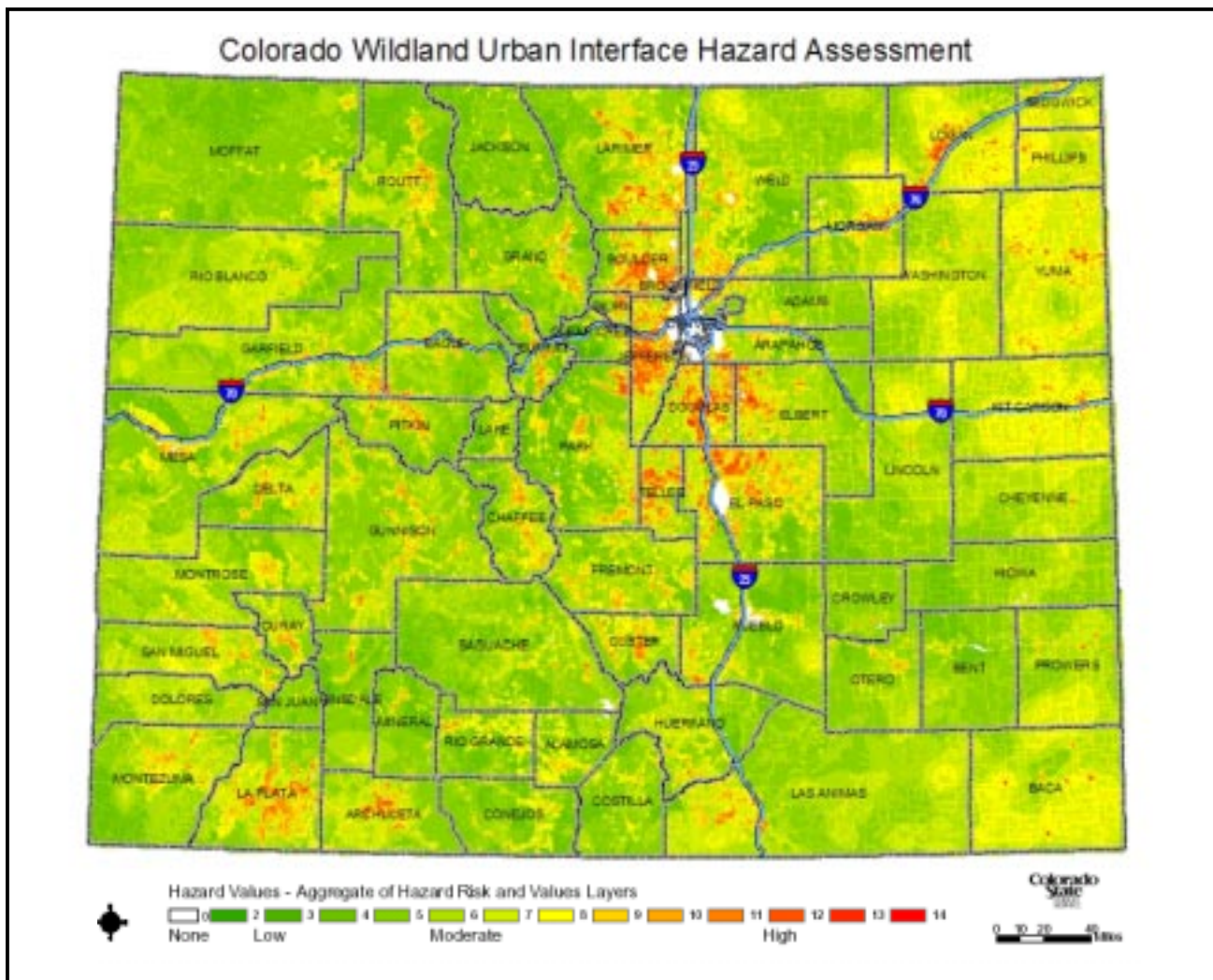
Based on the Mid-level wildfire assessment, March 1999 by the Colorado State Forest Service and Office of Emergency Management

The second risk assessment was completed in 2002 by the Colorado State Forest Service. Full details of the risk assessment, including the methodology and digital layers used, are included in the appendices. The map below was generated as a product of the assessment and indicates the wildland urban interface hazard assessment for the state. In reviewing the map, it becomes obvious that every county has some area with at least a moderate interface wildfire hazard.

To determine if your community is designated as a "community at risk" in the "Wildland Urban Interface Communities at High Risk from Wildfire," list, refer to www.stateforesters.org/WUI_list.html.



Home burned in the fire on Battlement Mesa. The fire was human-caused. Photo provided by the Colorado State Forest Service.



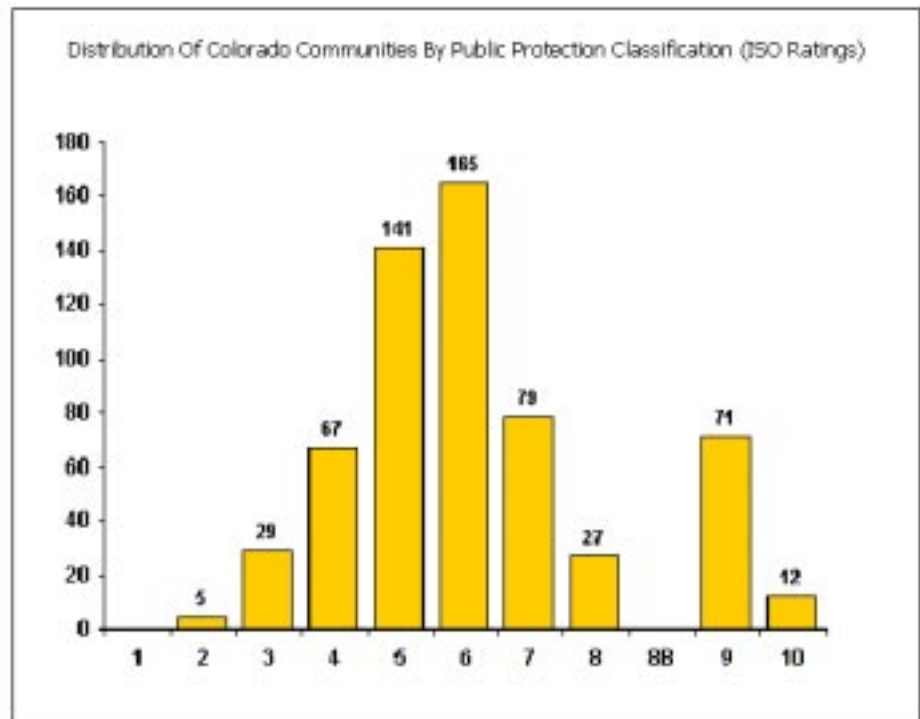
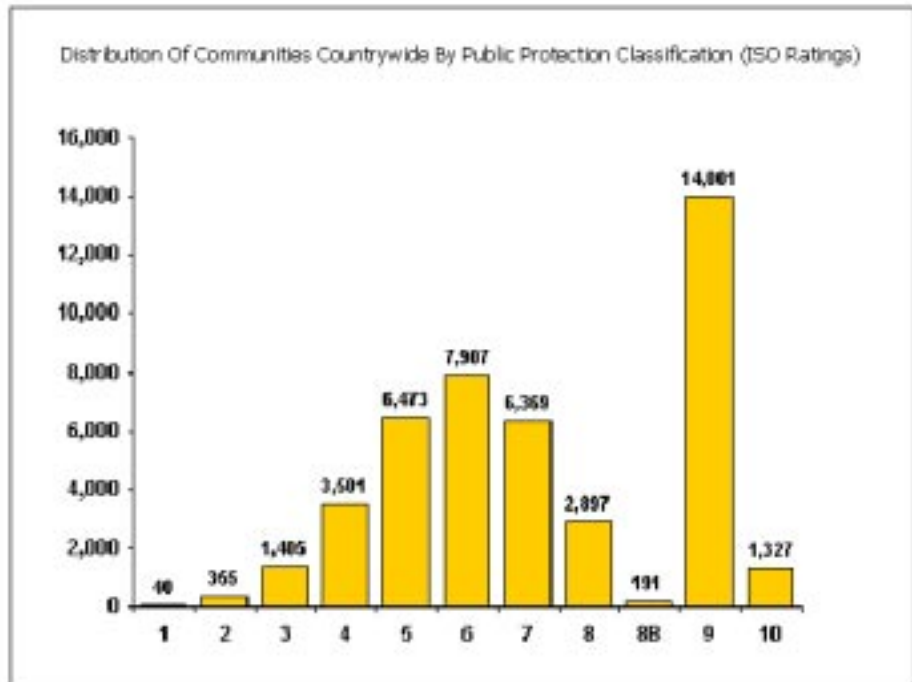
ISO RATINGS FOR COMMUNITIES

The Insurance Services Office, Inc., commonly known as ISO, is an independent group that serves insurance companies, fire departments, insurance regulators, and others by collecting and analyzing information about municipal fire protection efforts and grading the community with a Public Protection Classification (PPC). The program measures fire-suppression programs in 45,000 fire districts around the country.

The organization uses the Fire Suppression Rating Schedule manual. Classification ranges from 1 to 10, with Class 1 representing exemplary fire protection and Class 10 indicating that the area's fire suppression program does not meet minimum program criteria. Three factors are used to determine a community's grade: fire alarms (10 percent of grade), fire department (50 percent of grade), and water supply (40 percent of grade).

The fire alarm portion of the grade takes into account how well the fire department receives and dispatches fire alarms, including the number of operators, telephone service and lines, and the listing of emergency numbers in phone books. The fire department part of the grade looks at the number of engine companies and their distribution in the community, training of personnel, response to emergencies, and equipment maintenance and testing. Water supply considerations include sufficiency of water supply, rate of water flow at water mains, and distribution and condition of fire hydrants.

The two graphs below are reproduced from the ISO Mitigation Online website and may be found at www.isomitigation.com/fire9.html and www.isomitigation.com/ppcchart/colorado.html. According to the graph, 596 communities are rated in Colorado.



Floods

flooding - accumulation of water within a water body and the overflow of excess water onto adjacent floodplain lands (FEMA 1997).

floodplain - land adjoining the channel of a river, stream, ocean, lake or other watercourse or water body that is susceptible to flooding (FEMA 1997).

FLOOD FACTS

All states and territories are at risk from floods.

Overflow from river channels, flash floods, alluvial fan floods, ice-jam floods, dam breaks, high groundwater levels, debris flows, subsidence and changing lake levels can cause flooding.

Damage estimates from the 1993 floods in the Midwest were **\$21 billion**. Forty-eight deaths were attributed to these storms.

Floodprone areas have been identified in **268** cities and towns and most of the 63 counties in Colorado.

Over **250,000** people are living in Colorado's floodplains.

There are estimated to be **65,000** homes and **15,000** commercial, industrial, and business structures in identified floodplains in Colorado.

The value of the property, structures, and contents located in identified floodplains in Colorado is estimated to be over **\$11 billion**.

Colorado has had nine major flood disasters between 1965 and 1999:

- 1965: 33 Front Range communities
- 1969: 15 Front Range communities
- 1970: Southwestern Colorado
- 1973: 13 Front Range communities
- 1976: 2 Front Range communities
- 1982: Larimer County (dam failure)
- 1984: 15 Western Slope counties
- 1997: 13 Eastern Colorado counties
- 1999: 12 counties

(Sources: www.fema.gov/nfip/flossdp.htm; http://cwcb.state.co.us/flood_watch/floodplain.html; www.fema.gov/nfip/10409912.htm; www.fema.gov/nfip/flossp.htm; FEMA 1997)



Public Information Sign in a Canyon
Photo by David C. Marlin

One rescue worker lost his life in 2000 attempting to rescue people trapped during a flash flood in the Denver metropolitan area.

FLOOD HAZARD IN THE UNITED STATES

The following table lists reported deaths, injuries, and property and crop damage costs due to flash, river, and small stream/urban flooding in the United States for consecutive years from 1996 through 2003. Damages were over \$41 billion and 674 deaths were recorded.

SUMMARY OF REPORTED DEATHS, INJURIES, AND DAMAGE COSTS DUE TO FLASH, RIVER, AND SMALL STREAM/URBAN FLOODING IN THE UNITED STATES: 1996-2003				
YEAR	DEATHS	INJURIES	PROPERTY DAMAGE (\$ MILLION)	CROP DAMAGE (\$ MILLION)
1996	131	95	2,120.7	414.6
1997	118	525	6,910.6	116.9
1998	136	6,440	2,324.8	318.1
1999	68	301	1,420.7	371.7
2000	38	47	1,255.1	679.3
2001	48	277	1,220.3	43.0
2002	49	88	655.0	82.5
2003	86	70	2,543.1	158.1
TOTAL	674	7,843	41,338.2	2,184.2

Sources: www.nws.noaa.gov/om/severe_weather/

For complete information on floods in Colorado, refer to the **Colorado Flood Hazard Mitigation Plan 2004** at <http://cwcb.state.co.us>.

Every year, flooding causes hundreds of millions of dollars in damage to residences and businesses in the United States. Standard homeowners and commercial property policies do not cover flood losses. To meet the need, the federal government offers the National Flood Insurance Program (NFIP). Some companies, such as Lloyd's of London, also offer flood insurance. The NFIP offers flood insurance to communities that comply with standards for floodplain management. A flood does not have to be a declared disaster in order to make a claim on this insurance.

The following statistics are reported on the National Flood Insurance Program website:

In the United States, there are 4,206,914 flood insurance policies in the program.

In Colorado there are 14,795 policies.

From January 1, 1978 to December 31, 1999 (22 years), more than **1,000,000 losses** were reported in the United States. Loss payments were over **\$9.5 billion**.

Over the same period, Colorado policy holders made **1,717 claims** and received close to **\$7 million** in payments.

In Colorado, 30 properties have had repetitive flood losses.

Source: www.fema.gov/nfip/



New Canon City Detention Pond

Photo by Bill Archambault, COEM

The following table shows flood loss statistics by state for the period 1/1/78 through 12/31/99. Louisiana, Florida, and Texas had over \$4 billion in payments.

SUMMARY OF FLOOD LOSS STATISTICS IN THE UNITED STATES: 1/1/78-12/31/99		
STATE	NUMBER OF LOSSES	TOTAL PAYMENTS (\$MILLION)
Alabama	19,605	227.4
Alaska	258	2.1
Arizona	3,109	21.6
Arkansas	3,582	25.0
California	37,197	347.5
Colorado	1,717	6.9
Connecticut	12,712	92.8
Delaware	2,855	22.2
Florida	130,345	1,260.6
Georgia	9,081	114.3
Hawaii	3,193	53.2
Idaho	485	4.0
Illinois	28,985	191.9
Indiana	7,398	47.2
Iowa	5,668	51.2
Kansas	4,916	50.0
Kentucky	14,047	152.7
Louisiana	156,558	1,450.4
Maine	3,302	25.9
Maryland	6,542	45.0
Massachusetts	21,558	205.4
Michigan	7,604	29.9
Minnesota	7,473	84.0
Mississippi	27,431	221.7
Missouri	33,905	398.1
Montana	1,273	5.2
Nebraska	3,191	20.0
Nevada	1,099	24.9
New Hampshire	1,812	8.9
New Jersey	66,980	535.2
New Mexico	509	1.7
New York	65,268	352.9
North Carolina	46,534	502.4
North Dakota	8,631	124.8
Ohio	13,575	91.1
Oklahoma	7,672	87.9
Oregon	3,595	46.8
Pennsylvania	34,552	268.9
Rhode Island	2,538	18.0
South Carolina	25,549	407.0
South Dakota	1,433	11.9
Tennessee	4,772	31.3
Texas	121,523	1,390.2
Utah	696	4.7
Vermont	838	4.8
Virginia	14,631	135.0
Washington	7,259	92.0
West Virginia	15,602	154.6
Wisconsin	3,843	23.0
Wyoming	332	1.3

Source: www.fema.gov/nfip/

For complete information on floods in Colorado, refer to the **Colorado Flood Hazard Mitigation Plan 2004** at <http://cwcb.state.co.us>.



New Canon City Detention Pond

Photo by Bill Archambault, COEM

FLOOD HAZARD IN COLORADO

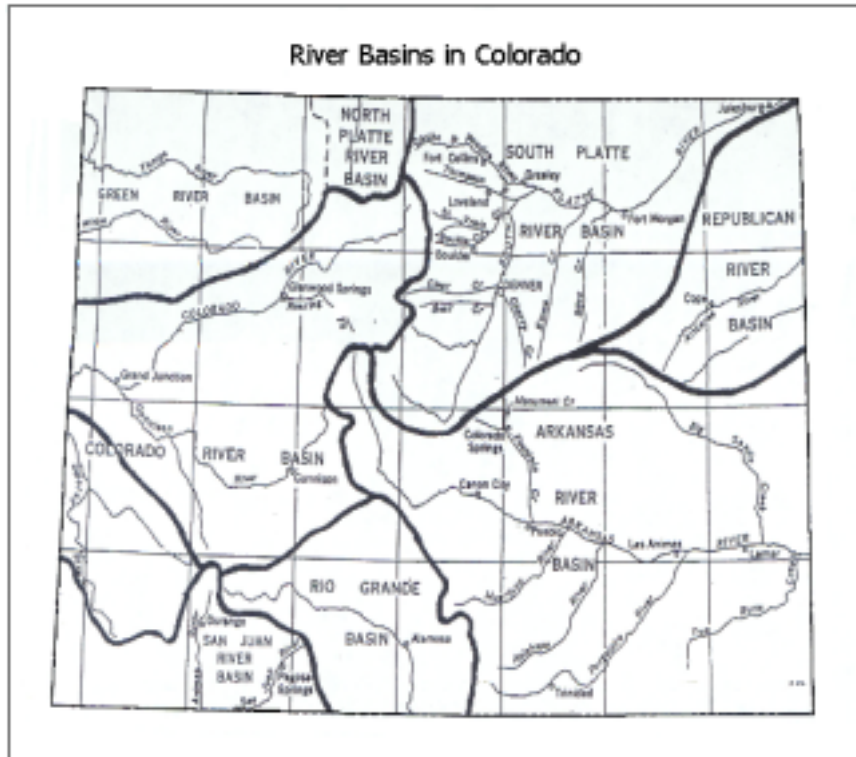
Colorado has a long history of tragic flooding events. The table to the right highlights major flood events in Colorado from 1864 through 1999. The greatest loss of life occurred during the Big Thompson flood event of 1976. In 1965, damages in Denver were evaluated at over \$2 billion (in 1999 dollars) due to a South Platte River flood event. Dams at Chatfield and Cherry Creek were built as a result of flooding events.

The map below depicts the water resources division boundaries for the state. There are seven regions. Resource boundaries are highlighted in blue. Municipalities (pink) and county boundaries (yellow) are also highlighted.

The table on the following page is a summary of damage in Colorado due to floods. The period is from January 1, 1978 through December 31, 1999. According to the National Flood Insurance Program statistics (www.fema.gov/nfip/10409912.htm), Colorado residents had 1,717 reported losses and received payments totaling close to \$7 million.

NOTABLE FLOOD EVENTS IN COLORADO: 1864-1999			
YEAR	LOCATION	DEATHS	DAMAGES (\$MILLION IN 1999\$)
1864	Cherry Creek (Denver)	?	6.0
1896	Bear Creek (Morrison)	27	6.0
1911	San Juan River (by Pagosa Spr.)	2	6.0
1912	Cherry Creek (Denver)	2	120.0
1921	Arkansas River (Pueblo)	78	760.0
1935	Monument Creek (Col. Springs)	18	52.0
1935	Kiowa Creek near Kiowa	9	15.0
1942	South Platte River Basin	?	8.5
1955	Purgatorie River (Trinidad)	2	36.0
1957	Western Colorado	?	18.0
1965	South Platte River (Denver)	8	2,200.0
1965	Arkansas River Basin	16	205.5
1969	South Platte River Basin	0	21.5
1970	Southwest Colorado	0	13.2
1973	South Platte River (Denver)	10	388.8
1976	Big Thompson River (Larimer)	144	85.2
1982	Fall River (Estes Park)	3	49.1
1983	North Central Counties	10	26.3
1984	West & Northwest Counties	2	46.5
1993	Western Slope	0	2.1
1997	Ft Collins & 13 East Counties	6	169.4
1999	Col. Springs, 12 East Counties	0	100.0
Totals		352	4,486.6

Source: Colorado Flood Hazard Mitigation Plan 1999



Adapted from Colorado Flood Hazard Mitigation Plan 1999

Upon FEMA request, the Colorado Water Conservation Board prepared an implementation plan for the Map Modernization of Colorado communities. Communities were prioritized based on certain factors including population in 2000, likelihood of floodplain mapping success, age of maps, CWCB evaluation of flood hazard risk, unmapped communities, wildfire impacts, and population growth from 1990 to 2000. Results were described as first, second, third and fourth priority counties.

The following table reveals the losses and payments to each community participating in the NFIP. This does not include uninsured losses or losses covered by another flood insurance.



Home Flooded in Otero County in 1999
Photo provided by the Colorado Water Conservation Board

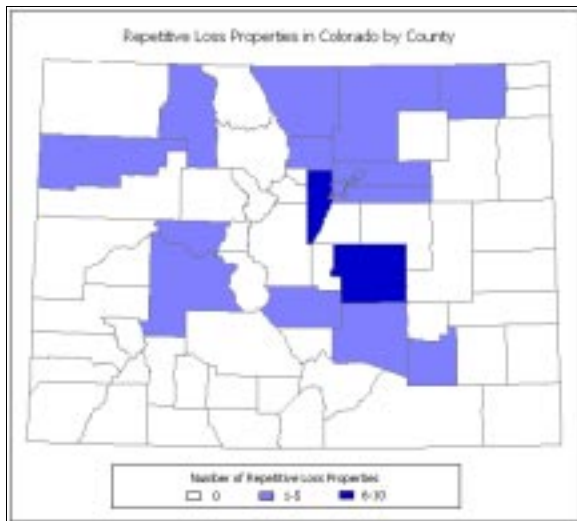
SUMMARY OF DAMAGE DUE TO FLOODS IN COLORADO: 1/1/1978-12/31/99								
COMMUNITY	LOSSES	PAYMENTS	COMMUNITY	LOSSES	PAYMENTS	COMMUNITY	LOSSES	PAYMENTS
Adams Co.*	15	21,896	Estes Park	34	659,587	Mineral Co.*	1	268
Alamosa Co.*	3	1,214	Federal Heights	2	12,773	Minturn, Town of	1	6,035
Alamosa, City of	13	9,225	Florence	1	1,208	Montezuma Co.*	1	0
Arapahoe Co.*	7	12,054	Fort Collins	39	341,452	Montrose Co.*	1	21,759
Archuleta Co.*	3	1,863	Fort Morgan	1	0	Montrose, City of	2	681
Arvada	41	35,345	Fountain	12	655	Morgan Co.*	5	22,112
Aspen	9	168,271	Frederick	5	10,349	Morrison	2	1,232
Aurora	31	816	Fremont Co.*	6	22,040	Otero Co.*	83	1,182,573
Basalt	1	3,816	Frisco	4	921	Ouray, City of	6	33,045
Bent Co.*	2	2,689	Garfield Co.*	6	5,228	Palmer Lake	2	0
Black Hawk	4	8,332	Georgetown	5	5,643	Paonia	9	51,261
Boone	2	26,147	Gilpin Co.*	2	1,462	Parker	1	0
Boulder Co.*	47	58,039	Glenwood Springs	7	26,398	Pierce	1	312
Boulder, City of	72	147,299	Golden	9	2,059	Pitkin Co.*	12	26,019
Breckenridge	2	28,060	Grand Junction	6	6,125	Prowers Co.*	7	2,783
Brighton	3	3,292	Greeley	5	63,895	Pueblo Co.*	20	62,492
Broomfield, City of	6	416	Green Mtn Falls	3	0	Pueblo, City of	45	34,634
Brush	17	2,970	Greenwood Vill.	1	1,080	Rangely	4	1,392
Buena Vista	2	1,007	Gunnison Co.*	25	126,836	Rifle	5	37,897
Calhan	1	0	Gunnison, City of	3	6,331	Rio Blanco Co.*	2	14,908
Canon City	38	52,016	Gypsum	1	0	Rio Grande Co.*	3	1,305
Central City	1	0	Hayden	2	1,236	Rocky Ford	7	25,803
Chaffee Co.*	2	0	Hinsdale Co.*	1	0	Routt Co.*	3	49,996
Clear Creek Co.*	8	14,595	Holyoke	1	2,244	Salida	1	1,310
Collbran	3	0	Hotchkiss	1	1,566	San Miguel Co.*	2	23,037
Colorado Springs	154	219,518	Huerfano Co.*	1	769	Silver Plume	2	1,460
Crested Butte	2	197	Idaho Springs	3	369	Silverton	1	1,144
Dacono	1	0	Jamestown	2	696	Steamboat Sprgs	12	4,460
Del Norte	1	1,346	Jefferson Co.*	62	150,902	Sterling	33	67,815
Delta Co.*	5	20,012	La Junta	28	431,257	Summit Co.*	10	7,873
Delta, City of	2	5,223	La Plata Co.*	4	1,442	Teller Co.*	2	0
Denver, City/Co.	100	352,371	Lakewood	101	367,639	Telluride	3	0
Dolores Co.*	1	270	Lamar	12	6,746	Thornton	5	6,417
Dolores, Town of	1	0	Larimer Co.*	93	551,652	Trinidad	2	2,004
Douglas Co.*	5	19,072	Limon	4	0	Vail	8	98,980
Durango	3	13,815	Littleton	17	15,896	Walsenburg	2	0
Eagle Co.*	10	6,811	Logan Co.*	18	131,814	Weld Co.*	22	57,970
Eaton	1	0	Longmont	9	2,260	Wellington	7	4,209
Edgewater	22	51,637	Loveland	5	7,986	Westminster	27	253,793
El Paso Co.*	76	180,283	Lyons	8	6,793	Wheat Ridge	32	81,537
Englewood	4	78	Manitou Springs	21	84,295	Windsor	1	0
Erie	2	986	Mesa Co.*	27	194,581	Winter Park	1	5,960
						Wray	1	0
*Unincorporated areas.						Total	1,717	6,918,649
Source: www.fema.gov/nfip/10409912.htm								

For complete information on floods in Colorado, refer to the
Colorado Flood Hazard Mitigation Plan 2004 at <http://cwcb.state.co.us>.



Building elevated in Morgan County
Photo by CDEM

According to FEMA National Flood Insurance Program information, the State of Colorado has 30 repetitive loss structures. Structures are located in 16 counties.



The following table was developed from information in the Community Information System, which is part of the Federal Emergency Management Agency database for the National Flood Insurance Program. Communities and unincorporated areas of counties participating in the program are asked to report on population and structures at risk and other items of interest. Some communities have not determined the population or structures at risk in their area. These are represented by zeroes. The numbers only reflect areas in the program. Statistics for individual areas are available.

POPULATION AND STRUCTURES IN FLOOD HAZARD AREAS			
COUNTY	POPULATION	1-4 FAMILY STRUCTURES	OTHER STRUCTURES
Adams	7,484	2,439	307
Alamosa	9,380	1,071	463
Arapahoe	6,635	1,834	257
Archuleta	290	46	9
Baca	0	0	0
Bent	0	0	0
Boulder	22,442	4,327	1,203
Chaffee	865	350	82
Cheyenne	55	0	0
Clear Creek	2,156	657	79
Conejos	1,688	403	10
Costilla	98	55	0
Crowley	68	42	0
Custer	0	0	0
Delta	1,733	195	48
Denver	2,079	738	571
Dolores	804	720	60
Douglas	300	100	3
Eagle	744	203	45
El Paso	9,749	3,732	1,028
Elbert	65	0	3
Fremont	9,590	3,319	201
Garfield	1,253	536	20
Gilpin	147	68	42
Grand	192	79	1
Gunnison	1,018	638	1
Hinsdale	19	45	16
Huerfano	751	315	0
Jackson	0	0	0
Jefferson	12,785	3,646	1,592
Kiowa	0	0	0
Kit Carson	0	0	0
La Plata	7,477	2,089	645
Lake	0	0	0
Larimer	6,159	2,488	288
Las Animas	375	160	110
Lincoln	549	135	37
Logan	3,676	3,635	313
Mesa	1,083	471	377
Mineral	60	150	0
Moffat	325	93	24
Montezuma	947	708	60
Montrose	1,241	408	6
Morgan	2,359	838	79
Otero	3,204	756	198
Ouray	265	149	98
Park	72	24	0
Phillips	424	119	0
Pitkin	211	76	20
Prowers	2,086	998	260
Pueblo	868	355	0
Rio Blanco	1,249	516	85
Rio Grande	1,030	342	5
Routt	939	201	146
Saguache	0	0	0
San Juan	14	12	11
San Miguel	723	245	55
Sedgwick	7	4	11
Summit	477	191	54
Teller	277	108	18
Washington	38	14	2
Weld	4,494	1,734	984
Yuma	715	389	15

Source: FEMA, Community Information System 1997

Approximately 27,000 dams exist in the State of Colorado. The Colorado Department of Natural Resources, Division of Water Resources, Office of the State Engineer concentrates on the 1,833 that are "jurisdictional" dams and reservoirs as defined in Section 37-87-105, C.R.S. (1999 Supp.). These are greater than ten feet high at the spillway or twenty acres in surface area or 100 acre-feet in capacity at the high water line. One hundred thirty-eight of these dams are federally owned, 1,695 are nonfederal, including private ownership. Three hundred and four are Class I dams, 305 are Class II, 1,024 are Class III, and 200 are Class IV.



Blue Mesa Dam
Photo provided by Alan Pearson, DWR

The Division of Water Resources runs the Dam Safety Program. A description of this program is in the State Assessment section under Department of Natural Resources Division of Water Resources.

According to FEMA Dam Safety information on the State Assistance Program, Colorado has Emergency Action Plans for 95 percent of the state-regulated high and significant-hazard potential dams. Only Virginia had more plans. Many states reported having no plans. For more information refer to www.fema.gov/mit/damsafe/assistance.htm.

The map and the table on the next page depict Class I and II dams in the state.

CLASSIFICATION OF DAMS	
CLASSIFICATION	DESCRIPTION
Class I	Loss of human life is expected.
Class II	Significant damage is expected, but not loss of human life. Significant damage refers to structural damage where humans live, work, or recreate or public or private facilities exclusive of unpaved roads and picnic areas. Damage refers to making the structures uninhabitable or inoperable.
Class III	Loss of human life and damage to structures and public facilities not expected.
Class IV	No loss of human life is expected and damage will only occur to the dam owner's property in the event of dam failure.

Source: Division of Water Resources 1988

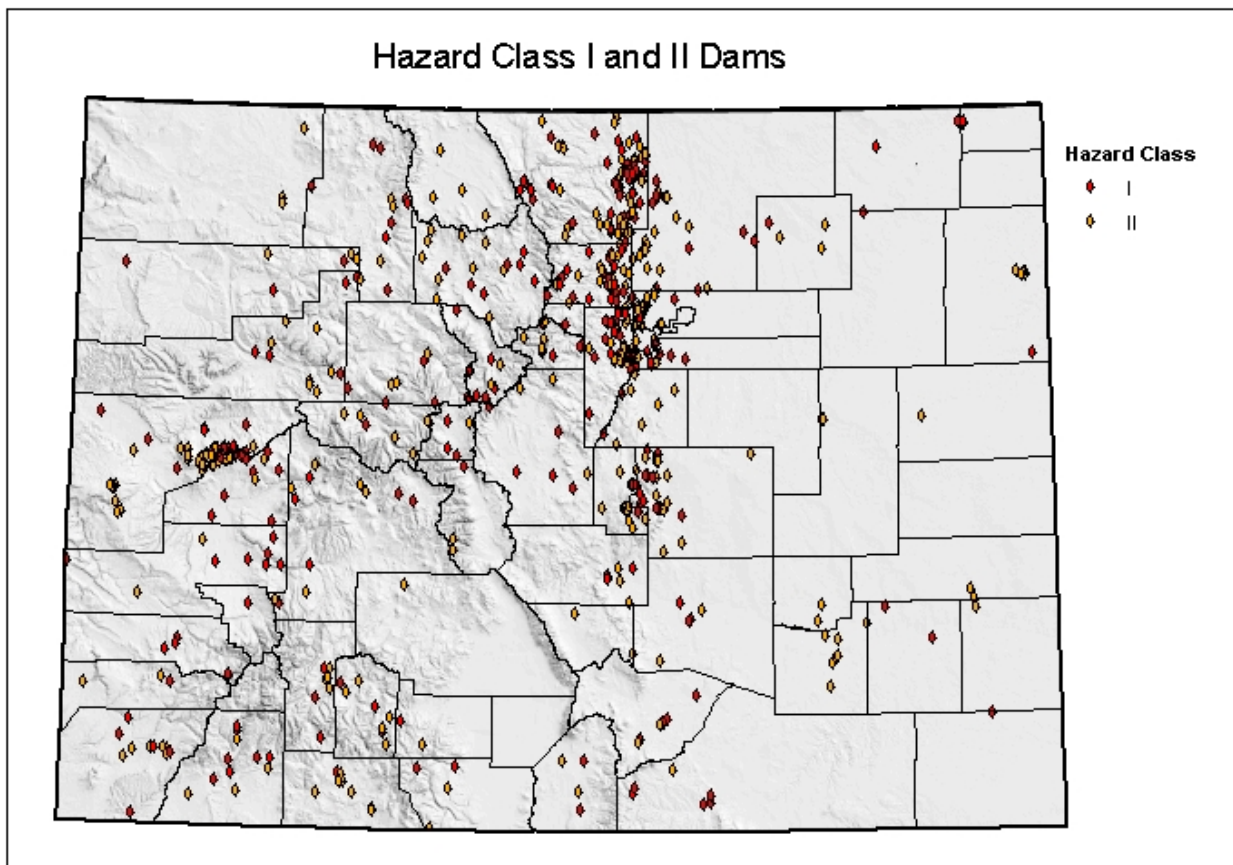


Cherry Creek Dam
Photo provided by U.S. Army Corps of Engineers

For more information on dam safety, refer to the Colorado Department of Natural Resources Division of Water Resources website at <http://water.state.co.us/dams.asp>.

CLASS I AND II DAMS IN COLORADO BY COUNTY					
COUNTY	CLASS I	CLASS II	COUNTY	CLASS I	CLASS II
Adams	7	11	La Plata	6	5
Alamosa	0	0	Lake	3	2
Arapahoe	5	4	Larimer	48	39
Archuleta	1	7	Las Animas	6	1
Baca	1	0	Lincoln	1	2
Bent	2	0	Logan	1	0
Boulder	23	17	Mesa	9	35
Chaffee	1	2	Mineral	3	7
Cheyenne	0	0	Moffat	1	3
Clear Creek	6	7	Montezuma	5	5
Conejos	2	2	Montrose	6	1
Costilla	2	2	Morgan	1	3
Crowley	0	2	Otero	0	7
Custer	0	0	Ouray	1	0
Delta	17	14	Park	5	3
Denver	7	3	Phillips	0	0
Dolores	1	2	Pitkin	2	4
Douglas	2	6	Prowers	0	1
Eagle	5	5	Pueblo	3	3
El Paso	11	17	Rio Blanco	2	3
Elbert	0	0	Rio Grande	1	1
Fremont	4	3	Routt	9	3
Garfield	6	7	Saguache	0	1
Gilpin	0	0	San Juan	0	0
Grand	9	9	San Miguel	4	0
Gunnison	6	4	Sedgwick	1	0
Hinsdale	3	3	Summit	5	2
Huerfano	5	3	Teller	4	10
Jackson	0	4	Washington	1	0
Jefferson	20	21	Weld	9	17
Kiowa	0	2	Yuma	1	6
Kit Carson	0	0			

Source: Division of Water Resources 2001



The map following this section depicts the counties in Colorado most at risk from flooding. Calculations were based on the following:

The population in the flood risk area as listed in the Community Information System database provided by FEMA. Values were assigned as follows:

<u>POPULATION IN FLOOD RISK AREA</u>	<u>VALUE</u>
1,001 +	3
501 – 1000	2
1 – 500	1
0	0

The numbers of structures identified as being in the flood risk area for each county were assigned a value as follows:

<u>NUMBER OF STRUCTURES</u>	<u>VALUE</u>
75+	3
50-74	2
22-49	1
1-21	0.1
0	0

The number of repetitive loss structures in each county as provided by FEMA:

<u>REPETITIVE LOSS STRUCTURES</u>	<u>VALUE</u>
7-10	3
4-6	2
1-3	1
0	0

The number of Class I and II dams in each county as provided by the Department of Natural Resources Division of Water Resources State Engineer's Office:

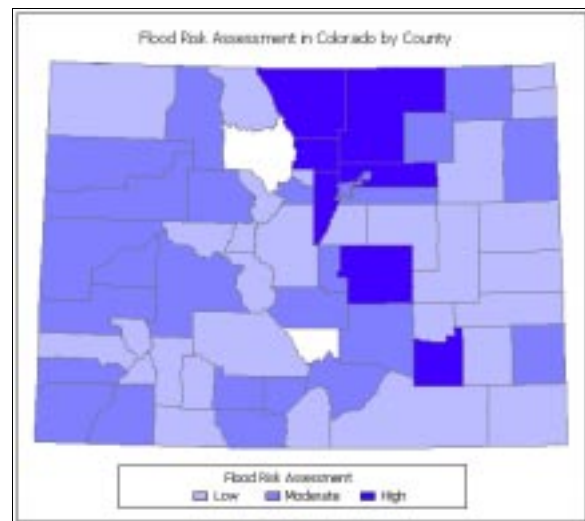
<u>NUMBER OF CLASS I & II DAMS</u>	<u>VALUE</u>
10+	3
6-9	2
1-5	1
0	0

The values of the four factors were totaled. Values were ranked as follows:

<u>VALUE</u>	<u>RISK ASSESSMENT</u>
10+	High
6-9	Moderate
1-5	Low
0	Very Low

The resulting values range from 0 to 12. Values from 10 through 12 represent areas determined to be at high risk. Values from 6 through 9 represent areas with moderate risk and values less than 5 represent areas with comparatively lower risk.

Mitigation activities in high-risk areas should have priority. High-risk areas include sections of Adams, Arapahoe, El Paso, and Weld Counties. Moderate risk areas include sections of Baca, Bent, Cheyenne, Douglas, Elbert, Kiowa, Kit Carson, Larimer, Lincoln, Logan, Morgan, Otero, Phillips, Prowers, Sedgwick, Washington, and Yuma Counties.



Mitigation activities should focus on improving communication, life safety activities, and floodproofing properties. Improving communications includes improving methods to alert persons to floods in the vicinity. Life safety plans should be encouraged in homes, schools, institutions, etc., and plans should be practiced regularly. Activities that involve making public and private property more flood resistant should be encouraged. Public education and information should be developed, improved, and disseminated on a continual basis. Communities at risk should be encouraged to develop flood plans.

Mapping priorities were determined by the CWCB. Four priority lists were created. First priority counties include Douglas, Eagle, Larimer, Elbert, Garfield, Weld, Boulder, Teller, Broomfield, Routt, Park, Adams, Denver, Arapahoe, Rio Grande, and Jefferson. Second priority counties are Fremont, Mesa, La Plata, Pueblo, Gunnison, Las Animas, Summit, El Paso, Prowers, Mineral, Archuleta, Morgan, Delta, Grand, San Miguel, and Custer. Third priority counties are Saguache, Rio Blanco, Pitkin, Ouray, Chaffee, Otero, Lake, Clear Creek, Montezuma, Logan, Phillips, Lincoln, Montrose, Hinsdale, Moffat, and Huerfano. Fourth priority are Gilpin, Crowley, Conejos, Dolores, Yuma, Alamosa, Washington, Sedgwick, Jackson, Cheyenne, Costilla, San Juan, Kit Carson, Bent, Baca, and Kiowa.

A flood acquisition project was funded after the 1999 presidential disaster declaration. In Otero County, 58 properties were acquired using CDBG, Unmet Needs program, and HMGP funds. Other flood mitigation projects have been done: La Junta lift station, Canon City retention ponds, Crowley floodproofing project, Fort Collins floodproofing project, Fort Collins and Pueblo early warning systems, Larimer County drainage improvements, and Otero County drainage improvements.

Hailstorms

hail - showery precipitation in the form of irregular pellets or balls of ice ..., falling from a cumulonimbus cloud.

cumulonimbus - a cloud of a class indicative of thunderstorm conditions, characterized by large, dense, and very tall towers. Also called thundercloud(s), thunderhead.

precipitation - falling products of condensation in the atmosphere, as rain, snow, or hail.

HAIL FACTS

Hail forms when water droplets freeze and thaw as they are carried up and down in updrafts and downdrafts in thunderstorms.

Hailstorms occur more frequently during the late spring and early summer.

An area in northern Colorado and southeastern Wyoming endures hailstorms 8+ days each year. Most inland regions experience hailstorms at least 2 or more days each year.

The Colorado plains are ranked #1 by the insurance industry for being hammered by hail.

In Denver on July 11, 1990, a hailstorm caused \$625 million in damage.

Hail is responsible for nearly \$1 billion in damage to crops and property each year in the U.S.

In July 1979, a baby hit by grapefruit-size hailstones in Fort Collins was killed and 25 others were injured, according to the Mountain States Weather Service.

Most hail is less than 2 inches in diameter. From 1/1/93 to 7/31/00, 123 hailstorm events were reported with hailstones 2 inches or larger; 11 with stones 3 inches or larger; and 4 with stones 4 inches or larger.

The largest hailstone ever recorded fell in Coffeyville, Kansas in 1970. It measured over 5.6 inches in diameter and weighed almost 2 pounds!

Hailstones can fall at speeds of 120 mph.

The National Weather Service considers a thunderstorm severe if it produces hail $\frac{3}{4}$ + inch in diameter or wind gusts 58+ mph or tornados.

Sources: National Weather Service, 2000; FEMA, 1997; www4.ncdc.noaa.gov/cgi-win/wwcgl.dll?wEvent~Storms; Rocky Mountain News, 6/12/99

HAILSTORM HAZARD IN COLORADO

The following is a summary of reported hailstorm events by county from 1/1/93 through 1/31/00.

SUMMARY OF HAILSTORM EVENTS, DEATHS, INJURIES, AND DAMAGE IN COLORADO BY COUNTY: 1/1/93 - 1/31/00				
COUNTY	NUMBER OF EVENTS	DEATHS	INJURIES	DAMAGE (\$MILLIONS)
Adams	52	0	0	155.0
Alamosa	7	0	0	1.0
Arapahoe	42	0	0	87.8
Archuleta	1	0	0	0.0
Baca	86	0	0	0.0
Bent	30	0	0	0.2
Boulder	49	0	0	1.0
Chaffee	2	0	0	0.0
Cheyenne	80	0	0	0.0
Clear Creek	4	0	0	0.0
Conejos	1	0	0	0.0
Costilla	3	0	0	0.7
Crowley	15	0	0	0.0
Custer	12	0	0	0.0
Delta	2	0	0	0.1
Denver	22	0	0	0.0
Douglas	29	0	3	3.0
El Paso	219	0	2	9.1
Elbert	48	0	0	0.0
Fremont	14	0	0	0.0
Garfield	1	0	0	0.0
Gilpin	1	0	0	0.0
Grand	2	0	0	0.0
Huerfano	10	0	0	0.0
Jefferson	51	0	0	0.0
Kiowa	83	0	0	0.5
Kit Carson	121	0	0	0.5
La Plata	1	0	0	0.0
Larimer	86	0	0	3.4
Las Animas	49	0	0	0.0
Lincoln	94	0	0	0.1
Logan	52	0	0	0.1
Mesa	5	0	0	0.8
Moffat	1	0	0	0.0
Montezuma	1	0	0	0.1
Morgan	82	0	2	4.7
Otero	49	0	0	0.1
Park	7	0	0	0.0
Phillips	37	0	0	0.5
Pitkin	1	0	0	0.0
Prowers	81	0	0	0.5
Pueblo	68	0	1	50.6
Rio Blanco	2	0	0	1.0
Rio Grande	7	0	0	0.0
Routt	2	0	0	0.2
Saguache	12	0	0	0.3
Sedgwick	27	0	0	0.0
Teller	17	0	0	0.0
Washington	72	0	0	1.2
Weld	176	0	0	33.0
Yuma	147	0	0	1.2
TOTAL	2,082	0	8	356.7
Source: www4.ncdc.noaa.gov/cgi-win/wwcgl.dll?wEvent~Storm				

Of the 2000+ events reported, there were no reported incidents for twelve counties. Counties with no reports are Delores, Eagle, Gunnison, Hinsdale, Jackson, Lake, Mineral, Montrose, Ouray, San Juan, San Miguel and Summit Counties. No deaths were reported during this period, but eight injuries were attributed to hailstorm events. For several counties such as Denver, Elbert, and Jefferson, events were reported but damages were not. El Paso County has the greatest number of events reported with 219, followed by Weld, Yuma, and Kit Carson Counties.

Hailstorms with high damage costs are listed in the following table. Damages from these storms were close to \$2 billion.

NOTABLE HAILSTORM EVENTS IN COLORADO: 1984 - 1998		
DATE	LOCATION	DAMAGE (\$MILLIONS)
6/13-14/84	Denver/Arvada	277
8/21/84	Pueblo	58
8/2/86	Denver/Fort Collins/Longmont	145
6/23/87	Pueblo/Fort Lupton/La Junta	79
7/11/90	Denver/Front Range	626
5/30-6/2/91	Metro Area	100
10/1/94	Denver	225
5/22/96	Adams & Jefferson Counties	122
6/21-22/96	Denver/Larimer County	100
8/11/97	Denver area	128
10/16/98	Arapahoe County/Buckley Field	88
6/8-9/04	Golden/SW Denver	(est) 100+

Source: http://www.rockymountainnews.com/drmn/local/article/0,1299,DRMN_15_688081,00.html, Rocky Mountain News 6/11/04

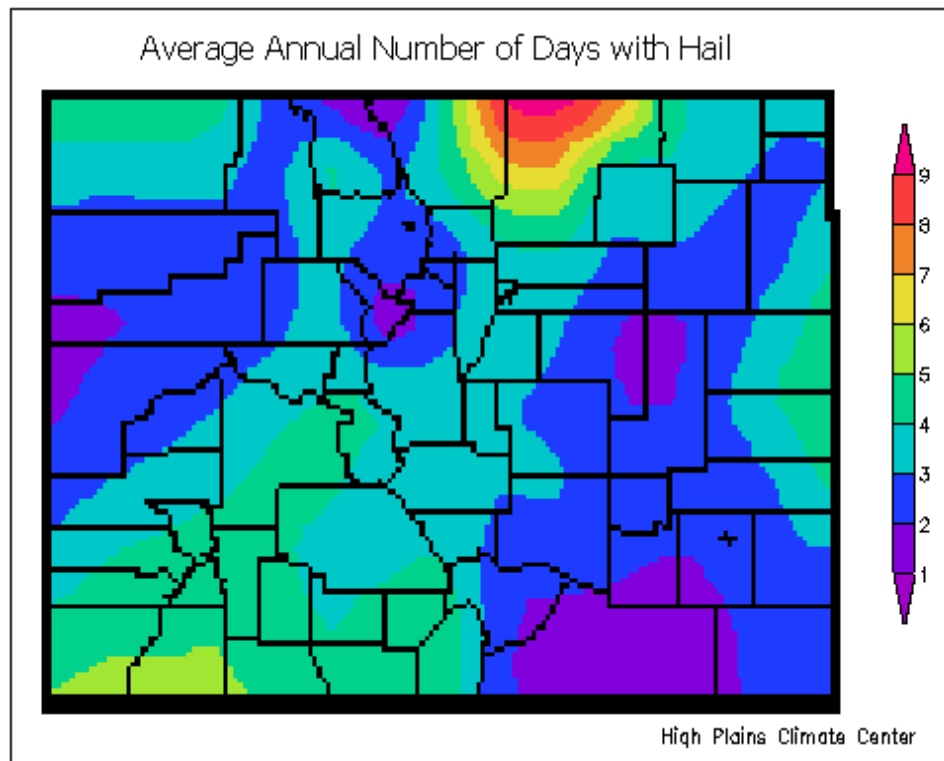
Many times the size of hailstones will be reported using everyday objects. Observers may use the table below when estimating the size of hailstones.

MEASURING HAILSTONES	
ESTIMATED SIZE	AVERAGE DIAMETER
Pea	1/4 inch
Marble/mothball	1/2 inch
Dime/penny	3/4 inch
Nickel	7/8 inch
Quarter	1 inch
Ping-pong ball	1 1/2 inch
Golf ball	1 3/4 inch
Tennis ball	2 1/2 inch
Baseball	2 3/4 inch
Tea cup	3 inch
Grapefruit	4 inch
Softball	4 1/2 inch

Source: www.nws.noaa.gov/er/cae/svrwx/hail/hail.html

The following map, originally created by the High Plains Climate Center and adapted to just show Colorado, depicts the average number of days per year with hail. The north-central area, specifically northeast Larimer and north Weld Counties, show the highest number of days in the state with 6 or greater.

"Long-stemmed vegetation is particularly vulnerable to damage by hail impact and accompanying winds. Severe hailstorms also cause ... damage to buildings and automobiles, but rarely result in loss of life."
 - from MultiHazard Identification and Risk Assessment, 1997



Adapted from <http://hpccsun.unl.edu/coop/atlas/hailann.gif>

Severe Hailstorm Events In Colorado: 1950-1996

LEGEND

- County Boundaries
- Severe Hailstorm Events 1950-1996

The map above depicts hailstorm events from 1950 through 1996. Data used to generate this map came from FEMA's Hazards U.S. software. Note the concentration of events in the eastern half of the state. The photos below show hailstorms in May 2003. Photos provided by the Colorado Division of Emergency Management.



Landslides and Rockfalls

landslide - downward and outward movement of slopes composed of natural rock, soils artificial fills, or combinations thereof. Common names for landslide types include slump, rockslide, debris slide, lateral spreading, debris avalanche, earth flow, and soil creep (Colorado Geological Survey (CGS)).

mud flow - a mass of water and fine-grained earth materials that flows down a stream, ravine, canyon, arroyo or gulch (CGS).

debris flow - if more than half of the solids in the mass are larger than sand grains-rocks, stones, boulders, the event is called a debris flow (CGS).

rockfall - the falling of a newly detached mass of rock from a cliff or down a very steep slope (CGS).

FACTS

Precipitation, topography, and geology affect landslides. Landsliding in areas of Colorado intensified during the 1980s due to higher than normal annual precipitation levels.

It is estimated that there are **thousands** of landslides in Colorado.

It is estimated that at least 18 damaging debris flow events have occurred in Glenwood Springs since 1900.

Garfield County, in 1985, recorded the largest debris flow in Colorado history, a 175-foot thick mass of debris a **mile** long and **1,000** feet wide.

Millions of dollars in federal emergency highway funds were used to restore highways damaged by landslides at Douglas Pass, Muddy Creek and other sites.

In the past 30 years, landslides have resulted in approximately 40 disaster declarations. According to FEMA, best estimates of losses attributed to landslides in the United States are 25 to 50 lives per year and **\$1-2 billion** in property damage.

Human activities trigger slope failures. Activities include mining and construction.

Landslides damage and destroy homes, roads, railroads, pipelines, electrical and telephone lines, mines, oil wells, commercial buildings, canals, sewers, dams, bridges, seaports, airports, forests, parks, and farms.

Sources: Colorado Geological Survey 1988; FEMA 1997

LANDSLIDE AND MUD FLOW/DEBRIS FLOW HAZARDS IN THE UNITED STATES

According to FEMA (1997), no state is free from the effects of landslides. The California coastal ranges, the Colorado Plateau, the Rocky Mountains, and the Appalachian Mountains have been identified as the areas where landslides most commonly occur. "The best estimates of annual losses resulting from landslides in the United States are 25 to 50 lives and \$1 to \$2 billion in property damage." Approximately forty presidential disaster declarations in the past twenty-five years have been landslide-related.

California, Washington, and Colorado are the first three states to use federal disaster funds for property acquisitions for landslide hazard areas.



Home Destroyed by Landslide in Colorado Springs
Photo provided by Colorado Springs Emergency Management

LANDSLIDE AND MUD FLOW/DEBRIS FLOW HAZARDS IN COLORADO

The following photograph demonstrates the serious nature of these hazards in Colorado. The structural integrity of this home was destroyed. The home was condemned and has been demolished.



Landslide Damage to Home in Colorado Springs
Photo provided by Colorado Springs Emergency Mgmt

The following is an overview of some events.

NOTABLE EVENTS IN COLORADO		
YEAR	LOCATION	DESCRIPTION
?	Near Lake City, Hinsdale Co.	Slumgullion earthflow dammed Lake Fork of Gunnison River, forming Lake San Cristobal.
1903	South of Glenwood Springs, Garfield Co.	Debris flow. Rainstorm caused mud and rock to cover a railroad line. Train wreck, one member of train crew killed.
1912	Brownville, Clear Creek Co.	Debris flows. Community engulfed and destroyed.
1914	Telluride, San Miguel Co.	Debris flows in Coronet Creek, flooding in San Miguel River.
1924	DeBeque Canyon	Landslide. Blocked Colorado River, resulted in forced relocation of a small community, highway and railroad.
1930s 1940s	Marble, Gunnison Co.	Debris flows. Town nearly destroyed.
1937	Glenwood Springs, Garfield	Debris flow. Much of town covered. Mud 2 feet deep.
1969	Telluride, San Miguel Co.	Debris flows in Coronet Creek, flooding in San Miguel River.
1976	Big Thompson Canyon, Larimer Co.	Interrelated landslide/ flood event. Mountain torrent flood.
1977	Glenwood Springs, Garfield Co.	Debris flow. Losses between \$500,000-\$1 million. 200 acres of residential district covered up to 14' deep.
1981- 1982	Ouray, Ouray Co.	Debris flows in Canyon, Cascade, Portland Creeks, etc. Flooding in Uncompahgre River.
1983, 1984	Dowds Junction, Eagle Co.	Landslides blocked I-70. Highway closed.
1984	15 Western Slope Counties	Floods and landslides. Declared disaster areas by President. Related to spring runoff. Over \$6.6 million spent in federal, state, and local disaster assistance.
1984	Grand Junction, Mesa Co.	Most homes in a subdivision affected. Some condemned.
1985	Two Western Counties	Floods and landslides. State emergency declaration. \$1.4 million in damages.
1999	El Paso County	Floods, mudslides, landslides. Presidential disaster declaration. Estimated over \$30 million in infrastructure and property damage, including road repairs and twisted utility lines. Several residences condemned.
Source: Colorado Landslide Hazard Mitigation Plan 1988, 2002		

For a more complete list, refer to the Landslide Hazard Mitigation Plan 2002 in the appendices.

LANDSLIDES

The following landslide sections are reprinted from the Colorado Geological Survey website at <http://geosurvey.state.co.us/pubs/geohazards/docs/landslides.asp>.

Landslides are the downward and outward movement of slopes composed of natural rock, soils artificial fills, or combinations thereof. Common names for landslide types include slump, rockslide, debris slide, lateral spreading, debris avalanche, earth flow, and soil creep.



Photos by Colorado Geological Survey

Characteristics

Landslides move by falling, sliding, and flowing along surfaces marked by differences in soil or rock characteristics. A landslide is the result of a decrease in resisting forces that hold the earth mass in place and/or an increase in the driving forces that facilitate its movement. The rates of movement for landslides vary from tens of feet per second to fractions of inches per year. Landslides can occur as reactivated old slides or as new slides in areas not previously experiencing them. Areas of past or active landsliding can be recognized by their topographic and physical appearance. Areas susceptible to landslides but not previously active can frequently be identified by the similarity of geologic materials and conditions to areas of known landslide activity.

Consequences

Landslides in the U.S. are estimated to cause more than \$1 billion a year in property damage, according to the Transportation Research Board of the National Academy of Sciences. Railroads, highways, homes, and entire communities are lost to landslides that demolish and/or bury them. In Colorado the 19th century mining camp of Brownsville just west of Silver Plume is buried beneath a rain-triggered landslide that became a debris flow. It is now under Interstate 70. Landslides occur commonly throughout Colorado, and the annual damage is estimated to exceed three million dollars to buildings alone.



Scarp of the Green Mountain Landslide
Photo by Colorado Geological Survey

Aggravating Circumstances

Landslides are one of the primary natural processes shaping the land. Human activities that frequently cause significant increases in landslide activity include:

1. Excavation of a steep slope or the toe of an existing landslide, thus removing support of the upslope mass,
2. Addition of material to the head (top) of a landslide which pushed the slide material downslope,
3. Addition of moisture to the landslide mass, increasing the weight and decreasing the strength

The activities that tend to increase landslide potential include excavation for highways and houses, lawn watering or surface drainage diversions, and changes in water infiltration rates. Alteration of surface land use such as road cuts and water impoundments, which allows more water into the subsurface of a slide-prone slope, is a major contributing factor in landslides.

Mitigation

Many methods of mitigation can be designed for active or potentially active landslide areas. These generally fall into four categories: 1) change of slope shape, 2) drainage management, 3) retaining structures, and 4) special

treatments. Change of slope shape methods include excavating the entire slide, benching, excavating the upper part of the slide increasing the weight and resistance to movement of the lower part of the slide (loading), and a combination of excavation and loading.

Land Use

The above mitigation techniques can be quite costly, particularly for large landslide areas, and are often used only as a last resort or to protect expensive structures. Even then they may be temporary and in the long run ineffective. In general, recognition and avoidance of landslide areas with all structural land uses is desirable. Significant earth moving or structural use of the land nearly always justifies a thorough analysis of the landslide potential prior to construction, landslide-prone areas are unavoidable and mitigation measures must be utilized to fit the circumstances.

Case History

In June 1977, a residential subdivision developer in Jefferson County dug a utility trench half way up a 100-foot long slope contrary to the recommendations of an engineering geology report. Surface water collected in the improperly located and constructed trench causing a landslide 100 feet across, 50 feet long and up to 6 feet deep. It is not known if the costly remedial measures will prevent additional sliding and damage to property in the subdivision.

Case History

A school in Eagle County was proposed for the toe of an old landslide. A geologic examination revealed natural hazards and the location of the multi-story school, football field and grandstand area was moved to a safe site. The estimated savings: \$3.5 million.

Case History

An area being planned as a subdivision in Summit County was engulfed in a matter of minutes by a mudslide caused by saturated soils below the Town of Breckenridge water reservoir and a beaver pond. Geologic investigation showed several similar slides had occurred previously. The property lost its prime value and extensive regrading and mitigation work was required. No structures were involved. Rerouting drainage, drying out the slope, regrading and preventive construction measures should mitigate future damage as the area is developed.

Case History

During heavy spring snowmelt in 1972, the municipal sewage disposal plant for the city of Cortez was threatened by sudden and massive "erosion" eating away at the bench upon which the plant was located. Emergency action by City of Cortez employees prevented impending severe damage to the plant and appurtenant facilities.

A geological study of the site during the crisis showed that the actual cause was not normal erosion, as had been originally supposed, but was a type of landsliding known as lateral spreading. A build up of groundwater developed during the runoff caused a weak soil at a depth of about 20 feet to liquefy. Outflow of the liquefied weak soil at depth caused collapse of overlying firm clays and the entire mixture of firm clay, liquefied soil, and water was washed down the stream course by runoff waters, allowing the process to continue.

Proposed reconstruction and enlargement of the facility recognizes the potentially serious geologic problems and it is being engineered to minimize the hazard. An eventual savings in excess of a million dollars may be realized.

Landslides: Definitions From CGS Special Publication 6

Many types of mass movement of natural material are included in the general geologic term "landslide." However, *for purposes of these guidelines the term will be restricted to mean those mass movements where there is a distinct surface of rupture or zone of weakness that separates the slide material from more stable underlying material.* Such slides involve en masse downward and outward movement of a relatively dry body of rock and/or surficial material in response to gravitational stresses. Other varieties of landslides that are treated separately in these guidelines include: 1) rockfall which involves either direct fall or forward rotation of a rock mass followed by free-fall and/or rolling, bounding, or rapid sliding motions with only intermittent contact with the ground surface; and 2) mud flows and closely related phenomena which involve movement by viscous flow of material with high water content and which may lack a distinct surface of separation between the moving mass and underlying more stable material.

Landslides as defined above include two major types: 1) Rotational slides which refer to all landslides having a concave upward, curved failure surface and involving a backward rotation of the original slide mass; and 2) translational slides in which the surface of rupture along which displacement occurs is essentially planar. Either type of landslides can involve various combinations of bedrock, broken bedrock, and unconsolidated surficial material, and the displaced material in either type of slide may be either greatly deformed or nearly intact.

Rate of movement of landslides varies from very slow to very rapid. They may be extremely small in extent or measurable in miles. Volumes of material

involved may range from a few cubic feet to millions of cubic yards. Landslides result from some change in the physical condition of an unstable slope area (see section of guidelines on potentially unstable slopes). Such changes may be natural or man-induced. Some of the major mechanisms that initiate slides are: removal of the toe or lower end of a potentially unstable slope (commonly known as "day-lighting"); removal of lateral support material adjacent to an unstable area; placement of additional material on the upper portion of an unstable area (commonly referred to as "loading"); weakening of clay or other fine-grained materials by wetting; weakening of natural cohesive forces by ground water circulating along potential failure surfaces; or decrease of stability by excessive pore water pressures within the slope-forming materials or along a potential failure surface. Other mechanisms include; redistribution of mass by erosion and deposition; chemical and physical weathering which may weaken slope materials; earthquake vibrations and release by erosion of stresses related to active faulting or past stresses "locked in" rock materials.

Many of the above-described disturbances that are capable of inducing land sliding of unstable slopes can result from activities of man. The most common activities of man that can produce land-sliding include: Excavations such as road cuts, quarries, pits, utility trenches, site grading, landfill operations, stockpiling of earth, rock or mine waste; alteration of natural drainage which may lead to increased runoff and erosion or to local ponding and saturation of potentially unstable slopes; and vibrations from blasting or heavy vehicular traffic.

Actual landslide movement can occur in several ways. It may be rapid, and of short duration, after which natural equilibrium (stability) of landslide material is achieved. It may consist of intermittent periods of active movement, separated by relatively inactive periods. A third possibility involves slow, continuous move-slide material may involve movement that can be measured in a few feet, or it may involve displacement measurable in hundreds or thousands of yards, and in some cases even miles. Differential movement may also occur within an active slide mass. Isolated smaller slides may take place within the body of a large slide during its movement (multiple sliding), or they may occur after much of the larger slide has stabilized. Also, the reverse is true, where large parent slides include, or incorporate, smaller slides.

Permanent features that commonly aid identifying the presence of old slides are the appearance of a main scarp and a corresponding bulge of landslide deposits on hillside. These features or relict anomalous slope changes often remain for many years as evidence of past instability. It should be noted that all such breaks in the natural profile of a hillside are not necessarily remnants of landslide scarps or deposits, and that determination of slope stability requires study by an experienced engineering geologist.

Rotational slides can occur anywhere that the following conditions are present, and in the necessary combination to promote sliding: 1) slopes sufficiently steep to allow lateral downslope movement of materials in response to gravity; 2) gravitational stress sufficient to move such material; 3) presence of unstable material susceptible to sliding; 4) underlying zone of weakness as a potential surface of rupture; 5) introduction of a disturbing factor – natural or man-made – sufficient to initiate instability and movement.

A translational landslide is characterized by a planar surface of rupture, and frequently by little deformation of slide material. Physical relationships prevalent in this type of slide are the presence of relatively competent materials above and beneath a planar zone of weakness along which sliding occurs. This condition is quite common in nature and may be the result of various combinations of materials and/or physical conditions. Translational slide material may range from fairly loose unconsolidated soil to extensive slabs of hard, resistant rock. Movement of translational slide material may be initiated by a variety of conditions, which are listed under general description of factors tending to produce land sliding.

The same criteria outlined above as prerequisites for rotational sliding to occur, apply to translational gliding, with the exception of item 3. In contrast to rotational slides, the entire slide mass in a translational slide need not necessarily be weak, unstable material itself – there may be very thin zone of weakness such as thin layer; bedding, joint or foliation plane; or the surface separating weak surficial material from underlying competent material.

Severity of problem

Landslides are widespread, naturally occurring geologic events through much of Colorado. Only when such phenomena conflict with the works of man do they constitute a serious problem or hazard. The severity of such a problem is directly related to the extent of man's activity in areas affected, and adverse effects can be mitigated by early recognition and avoidance or by corrective engineering. Actual losses can range from mere inconvenience or high maintenance costs where very slow or small-scale destructive slides are involved.

Rapidly moving large slides have the capacity to completely destroy buildings, roads, bridges, and other costly manmade structures. Such slides also have the potential for inflicting loss of life when they occur in developed areas. Occurrence of landsliding is widespread throughout the mountainous and hillier regions of the state, and countless slides take place annually. Costs in terms of road maintenance in slide areas, building damage, lost time on construction projects, inconvenience, and in some cases threat to life are large. Where man's activities invade areas of high landslide potential, this becomes one of Colorado's most severe geologic hazards.

Criteria of Recognition

Some indications of past sliding in an area are: erratic

drainage patterns, trees growing in disarray at divergent angles; irregular, hummocky, poorly drained ground surface; anomalous slope changes described earlier; and disturbed or displaced cultural features such as roads, walkways, and buildings. Recognition of potentially unstable slopes is treated in a separate section of the guidelines.

Consequence of Improper Utilization

The consequence of improper utilization of areas subject to landslide for building and development may range from minor damage in extremely fortunate cases, to total destruction of structures and accompanying loss of life. Maintenance of structures in active slide areas is very costly, and in many cases will equal or exceed the price of the structure prior to expiration of its useful life.

"Colorado's vulnerability to the landslide hazard is largely a consequence of the increasing expansion of commercial and residential development onto steep or unstable terrain that is prone to landsliding."

-From Colorado Landslide Hazard Mitigation Plan 1988

Mitigation Procedures

Having properly identified a region as being prone to landslide failure, several approaches can be taken in attempting to utilize the area.

Avoidance

Some non-conflicting use could be designated for the area, whereby losses would be minimal in the event of failure. One such use is green belting, or open space including certain types of agricultural use.

Non-conflicting use

Where the proposed use is simply not compatible with an existing slide hazard, the hazard is best avoided by selective use of available development land and complete avoidance of high-risk areas.

Rotational Slide Terminology

Main scarp: steep undisturbed ground surface above the highest part of the slide, resulting from downward movement of slide material.

Minor scarp: steep surfaces in slide material resulting from differential movement within the body of the slide.

Crown: in-place material just above the main scarp.

Head: uppermost part of slide material along the contact between the main scarp and the slide material.

Transverse cracks: tension cracks more or less perpendicular to the direction of slide movement, generally resulting from downward and outward movement of slide material over a hump in the rupture surface.

Radial cracks: tension cracks resulting from lateral spreading of unconfined slide material.

Tip: furthest forward extension of slide material.

Toe: furthest forward margin of slide material.

Foot: contact between original ground surface, and lowermost extension of surface of rupture.

Surface of rupture: projection of main scarp surface beneath the slide mass.

Right flank: right extent of slide as viewed from the crown, looking down onto the slide.

Left flank: left extent of slide as viewed from the crown, looking down onto the slide.

Prevailing slope: direction of predominant ground surface slope in undisturbed area.

Original ground surface: undisturbed ground surface surrounding disturbed slide area.

Longitudinal fault zone: faulting resulting from differential forward progress of downward moving slide material.

Engineered design and construction for correction of adverse conditions

Where economic pressures and limited available land militate for use of unstable or potentially unstable areas another alternative is to develop moderately unstable areas *under specified and closely controlled conditions*. This approach calls for careful evaluation of the physical extent, seriousness, and causes of geologic problems, and strict adherence to recommended design and construction procedures, as set forth by competent professional geologists and professional engineers evaluating the landslide area.

There are several common preventive methods employed to avoid sliding. One is to refrain from removing natural support material in the area immediately beneath or adjacent to the slide area. Another is the addition of artificial support material to this area. Such support can be in the form of rock- or earth- fill buttressing, retaining walls or cribbing, concrete slurry, rock bolting and reinforced pilings.

Another approach is to permanently improve and control surface and subsurface drainage in the vicinity of a potential slide area. This greatly decreases the lubricating and pore water pressure effects of water, and accompanying decrease in stability. This approach is often very effective, however, it may involve complex de-watering systems and costly long-term maintenance and monitoring problems.

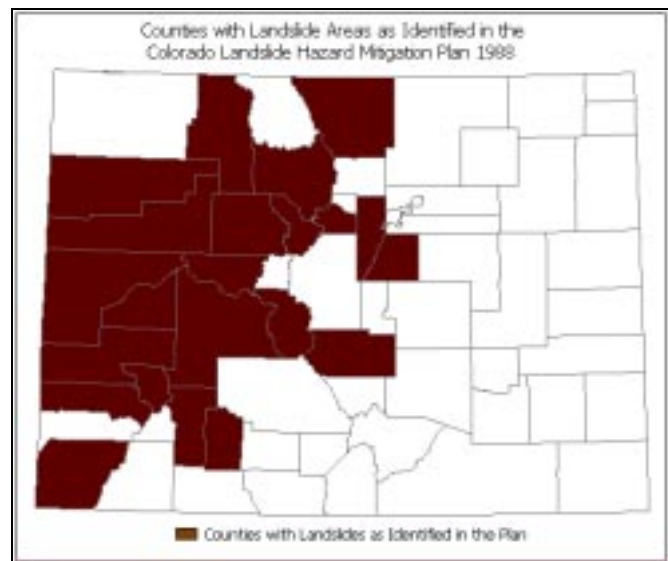
Other alternatives include stabilizing the slide area by chemical treatment, bridging weak zones, removal of unstable material, and avoidance of loading on unstable areas.

In summary, it should be stated that landslides, and landslide-prone areas can be very complex in nature, and pose serious risks to any development placed in their vicinity.

Only competent professional engineering geologists and soil engineers should evaluate landslides and potential slide areas. The information contained in the guidelines is only an introduction to the subject.

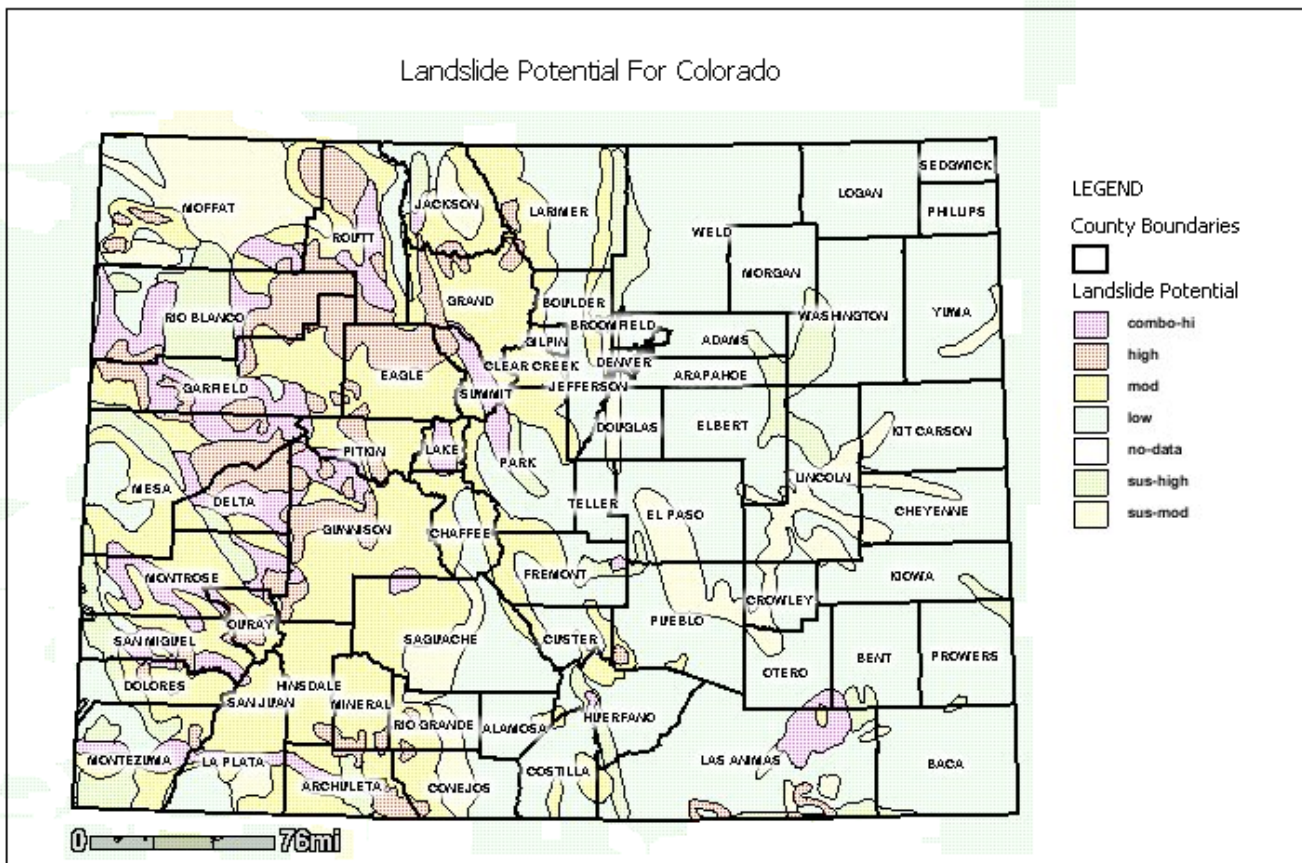
As noted in the Colorado Landslide Hazard Mitigation Plan (1988), 49 areas have been identified as having the "most serious or immediate potential impacts on communities, transportation corridors, life lines, or the economy."

The following counties have landslides identified in the plan: Chaffee, Clear Creek, Delta, Douglas, Eagle, Fremont, Garfield, Grand, Gunnison, Hinsdale, Jefferson, Larimer, Mesa, Mineral, Montezuma, Montrose, Ouray, Pitkin, Rio Blanco, Routt, San Miguel, and Summit. Refer to the Landslide Plan for locations and details on the landslides. Included in the plan are the community/ areas affected, the type of landslide, facilities at risk, and mitigation activities. The Colorado Geological Survey has determined that twelve large landslides have "high potential for very large future losses". The map to the right illustrates the counties.



Two landslide acquisition projects were completed as a result of presidential disaster declaration DR-1276-CO. Four homes were acquired in Manitou Springs and 25 homes in Colorado Springs. Federal funds from the Hazard Mitigation Grant Program and Unmet Needs were used. Loans from the Small Business Administration were also received.

The map below was created from information in the HAZUS-MH database.



MUD FLOW/DEBRIS FLOW: *From CGS Special Publication 12*

A mud flow is a mass of water and fine-grained earth materials that flows down a stream, ravine, canyon, arroyo or gulch. If more than half of the solids in the mass are larger than sand grains—rocks, stones, boulders—the event is called a debris flow.

Characteristics

Debris and mud flows are a combination of fast moving water and a great volume of sediment and debris that surges down slope with tremendous force. The consistency is like that of pancake batter. They are similar to flash floods and can occur suddenly without time for adequate warning. When the drainage channel eventually becomes less steep, the liquid mass spreads out and slows down to form a part of a debris fan or a mud flow deposit. In the steep channel itself, erosion is the dominant process as the flow picks up more solid material.

A drainage may have several mud flows a year, or none for several years or decades. They are common events in the steep terrain of Colorado and vary widely in size and destructiveness. Cloudbursts provide the usual source of water for a mud flow in Colorado.

Consequences

Mud/debris flows ruin substantial improvements with the force of the flow itself and the burying or erosion of them by mud and debris.

The heavy mass pushes in walls, removes buildings from foundations, fills in basements and excavations and sweeps away cars, trucks heavy equipment and other substantial objects. Boulders and trees swept along by the muddy mass demolish buildings, & flatten fences and utility poles. In mountain areas, portions of valleys have been eroded to a depth of several feet by the flow process.

Aggravating Circumstances

The likelihood of mud flows and mud flow damage is increased by actions that increase the amount of water or soils involved. Removal of vegetation on steep slopes, dumping debris and fill in a mud flow path and improper road building or earth moving can contribute to a mud flow. The failure of a dam, irrigation ditch or other water management structure can initiate mud/debris flow if the escaping water can swiftly accumulate a large volume of soil materials. Similarly, a landslide that temporarily blocks a stream may cause or contribute to a debris flow.

Mitigation

In most instances very little can be done to mitigate the mud flow process in the channel itself. Recognizing natural mud flow areas and avoiding them can prevent property damage. In some cases unstable slopes can be revegetated or reinforced to reduce the effect of large volumes of moving water upon them. A series of check dams or other storm drainage management practices may be considered in some cases. Geologic investigations can identify areas of mud flow potential and serve as a guideline for development of mitigation plans.



Debris Fan in Garfield County
Photo by Colorado Geological Survey

Legal definition *From CGS Special Publication 6*

H.B. 1041, Part 1, 106-7-103 (12) defines a mud flow as follows: "Mud flow" means the downward movement of mud in a mountain watershed because of peculiar characteristics of extremely high sediment yield and occasional high runoff. H.B. 1041, Part 1, 106-7-103 (4) defines a debris-fan floodplain as follows: "Debris-fan floodplain" means a floodplain that is located at the mouth of a mountain valley tributary stream as such stream enters the valley floor.

Descriptive definition

A mud flow is a geologic phenomenon whereby a wet, viscous fluid mass of fine-to coarse-grained material flows rapidly and turbulently downslope, usually in a drainageway. This results typically from torrential rainfall or very rapid snowmelt runoff that initiates rapid erosion and transport of poorly consolidated surficial materials that have accumulated in the upper reaches of the drainage area. Included in this complex process are such strict terms as earthflow, mud flow, and debris flow (A.G.I., Varnes, 1958). Very high viscosity usually results in slow earthflow movement or a combination of slow movement and internal fracturing of landslides.

Fluvial (water) transport of materials is characterized by flow of very low viscosity water and fine-grained sediments in suspension.

Mud is composed predominantly of silt and clay, whereas the term "debris" is commonly applied to material that consist mostly of boulders and cobbles mixed with displaced soil and vegetation.

Mud flows are typically recurrent event in certain drainage basins. The combination of climatic and geologic conditions that produces mud flows is a characteristic of mud flow-prone drainages. The moving mixture of water, soil, rock and vegetation most commonly has the consistency of freshly mixed concrete. As it moves down a drainageway, a mud flow may incorporate nearly anything in its paths – trees, rocks, and debris left by previous flows, that in turn increase the erosive power and destruction energy of the moving mass. In the lower reaches of the drainageway, the stream channel may be deeply eroded, overrun and flooded by the flow, or filled, and the location and configuration altered.

A debris fan is a triangular-shaped landform that forms by deposition of material at the intersection of a tributary valley with a larger valley. The material consists of stream-flood sediments and/or mud flow material and is deposited where the stream changes gradient as it enters the larger valley.

Like the mud flows to which they are related and sometimes associated, flooding and deposition of material on debris fans are recurrent events. The cause of flooding is a cloudburst, extended rain or rapid snowmelt followed by rapid runoff into the drainage-way. As the water and associated debris move downstream, they pick up and carry large amounts of material—rocks, vegetation, soil, and at times man-made works. Farther downstream, where the drainage course is less confined by valley walls and where the stream gradient is lower, the water spreads out into multiple channels. It is this area, typically near or at the mountain front, that is called a debris-fan floodplain. At this point stream and debris velocities are lower, and there is insufficient energy to move the debris. The debris load is deposited as a mixed mass forming the debris fan, and the water progressively changes from multiple-channel flow to sheet flow.

Most mud flows in Colorado originate in drainage basins that head in high barren mountainous areas. Such areas are more susceptible to erosion by rapid runoff than are gentler, vegetated slopes. Associated debris fans and their flood plains occur mostly along mountain fronts and steep valley sides.

Severity of problem

Mud flows become a serious threat to man-made works and human life when man inadvertently chooses to live in active mud flow areas. Mud flows can occur with no more advance warning than a rising storm cloud or rapid increase in springtime temperature. Most Colorado mud flows occur in the spring and summer, the months of great snowmelt runoff and rainfall.

Many scenic mountain valley areas in Colorado are under intense development pressure. The uncertain periodicity of mud and debris flows and floods, combined with the short memories of people can result in very dangerous circumstances if these mud flow prone areas are developed.

Because debris fans and mud flows are genetically related, problems associated with them are similar. The location of debris fans at mountain fronts makes them more accessible to people and development pressure.

Criteria for Recognition

Nearly all mud flow areas in Colorado are located in the lower parts of tributary streams of major streams as they enter the major valley. They are most easily recognized by occurrence of recent mud flow deposits and by the distinctive undulating topography of the fan areas. The maximum extent of these deposits and the associated fan represents the probable maximum extent of mud flows and danger. This is true even though some parts of the fan may be covered by vegetation, indicating temporary inactivity. Mud flow material is a heterogeneous mixture of mud, angular pebble- to boulder-sized or larger rocks, soil, vegetation, and coarse debris of trees. The top of a mud flow or debris fan is usually rough to undulatory when larger sized material predominates and relatively smooth if most of the material in the flow is fine grained. The color and composition of the flow material is commonly similar to the predominant bedrock near the upper reaches of the drainage basin from which it was derived. At the edge of the flow area, there is a pronounced transition from disturbed vegetation and undulatory ground surface to normal vegetation and slope conditions. The most recent mud flows are nearly devoid of vegetation. The gross appearance of the mud flow area is most commonly a mud and debris-laden streambed terminating down valley as a fan in the depositional area. In the case of certain drainages that carry a large volume of water as well as occasional mud flows, the stream may cut its channel deeply into the fan rather than shifting channels constantly. In such cases the typical debris-fan topography is absent or not easily recognized and the mud and debris may be deposited in or near the stream occupying the major valley.

Preliminary recognition of debris fans is aided by their location near mountain fronts, their irregular surface, the multiplicity of small stream channels on their surface, their triangular (fan) shape, poorly sorted deposits typical of debris flows. Other criteria for recognition include bruised and/or partially buried standing trees. Careful inquiries may provide documentation of historic occurrences.

Consequences of Improper Utilization

The consequences of improper utilization of mud flow and debris-fan areas range from occasional inconvenience to human inhabitants to loss of life and total destruction of all works of man in the area affected. Few mud flow-prone areas are suitable sites for construction of permanent structures. The unpredictable nature and often rapid movement of mud flows makes even the location of semi-permanent structures, such as mobile homes, extremely

hazardous. Even in cases where either frequency or magnitude of mud or debris flows is such that some development is acceptable, the nature of old mud flow deposits is uncertain, and normal human activities such as excavations and lawn irrigation could upset and possibly reactivate movement of the deposits. In addition many fan areas have very high seasonal water tables that can adversely affect on-site sewage disposal and other planning considerations.

In general, the more hazardous mud flow and debris flow areas should be avoided. In less severe cases, careful mitigation measures and compatible kinds of development are recommended.

Mitigation Procedures

Mud and debris flows can be channelized, diverted, or in some cases dammed, although the cost may be very high relative to the amount of real protection afforded. The principal difficulties associated with engineering structures to control mud flows are related to the great volume and mass of material contained in the flow. Because most of the flow consists predominantly of heavy solid matter, structures must be physically very strong and consequently expensive. Debris basins will fill and become ineffective unless cleaned out after each flow. Channelization may be effective in some cases, but this usually diverts the mud flow into the nearest stream or adjacent property to become a problem at a different location. In many cases, the unpredictability of which channels will act as distributaries for future flows makes siting of protective structures conjectural. In less severe cases, combinations of channelization, diversion dikes, and special foundations may be acceptable. In such cases careful geologic evaluations and engineering designs will be essential.



Falling Rock Sign on Highway 6
Photo by David C. Marlin

ROCKFALL: From CGS Special Publication 12

Rockfall is the falling of a newly detached mass of rock from a cliff or down a very steep slope. Rocks in a rockfall can be of any dimension, from the size of baseballs to houses.

Characteristics

Rockfalls are the fastest type of landslide and occur most frequently in mountains or other steep areas during early spring when there is abundant moisture and repeated freezing and thawing. The rocks may freefall or carom down in an erratic sequence of tumbling, rolling and sliding. When a large number of rocks plummet downward at high velocity, it is called a rock avalanche.

Rockfalls are caused by the loss of support from underneath or detachment from a larger rock mass. Ice wedging, root growth, or ground shaking, as well as a loss of support through erosion or chemical weathering may start the fall.

Consequences

Rockfalls can demolish structures and kill people. Rocks falling on highways may strike vehicles, block traffic, cause accidents, and sometimes damage the road. Minor but costly consequences is the work of clearing highways and borrow ditches in rockfall areas. Any structure in the path of a large rockfall is subject to damage or destruction.



The area and damage of the Booth Creek Rockfall of March 1997. The town of Vail is below the cliffs above Booth Creek. The cliff is the origin of the boulder that damaged houses in the town below.

Photo by Jon White, Colorado Geological Survey

Aggravating Circumstances

Man's activities often cause rocks to fall sooner than they would naturally. Excavations into hill and mountainsides for highways and building frequently aggravate rockfalls. Vibration from passenger trains or blasting can trigger them, as can changes in surface and ground water conditions. Rockfalls have been attributed to earthquakes and sonic booms.



The image shows the damage created by the falling boulder in the Booth Creek Rockfall. Photo by Jon White, Colorado Geological Survey.

Mitigation

The best way of dealing with rockfalls is to stay out of areas where rockfalls are naturally prevalent. If highways or other activities put people in rockfall areas, expensive methods can be utilized to decrease the likelihood and severity of rockfall damage. Some methods are removing unstable rocks, securing rocks to the slope so they will not fall and sheltering the improvements with earthen berms, fences, or other structural protection. In some instances of existing development, monitoring devices can be installed to warn approaching traffic of a rock fall. This measure could save lives, but will not protect property.

Land Use

The most appropriate land use in rockfall hazard areas is open space. Land development beneath or within rockfall areas should include evaluation of the hazards during the planning stage so structures can be located where rockfall damage is minimized. Unstable rocks can be removed or stabilized at considerable cost. In many cases periodic rock removal is necessary.

Case History

Two large rock masses loom precariously on the mountainside above the town of Silver Plume. One imperils the post office; the other a saloon; and anyone or anything in their path. Natural processes are at work and eventually both of the rock slabs will fall. Mitigation measures could include moving objects in their paths or deliberately initiating the falls to avoid loss of life. The town has been notified of the hazards and is contemplating the solutions.

Case History

In March 1974, a boulder the size of a small car hurtled down the steep west side of the Lyons hogback in Jefferson County. It bounced into a new subdivision and stopped after penetrating a wall in the back of an expensive home. No one was injured. Property damage was about \$10,000, including the cost of measures to prevent similar incidents at that site in the immediate future. The incident could have been prevented easily in the subdivision development stage but it was not recognized.

Legal definition: *From CGS Special Publication 6* H.B. 1041, Part 1, 106-7-103(8) Rockfall is defined only as a kind of geologic hazard.

Descriptive definition

In a rockfall, relatively large fragments of rock become detached and by means of free-fall, rolling, bounding or rapid sliding, or a combination of these methods, moves rapidly down a very steep slope under the force of gravity. Rockfall can be a continuous process over a considerable period of time or a single or series of single, intermittent events. Simultaneous activation of a large mass of rock can result in a rockfall avalanche or very rapid down slope and spreading movement of a large quantity of rock material. Rockfall can be initiated by several means. Most commonly this includes exposure to multiple freeze-thaw cycles, precipitation wetting and weakening of material under blocks, seismic activity, or undercutting of cliffs by erosion or flow of weak rock material.

Rockfall is common where there are cliffs of massive broken, faulted, or jointed bedrock; or where steep bedrock ledges are undercut by natural processes or activities of man. A major cause of rockfall is the repeated freeze-thaw action of water. Because freezing water expands, it develops pressures capable of wedging apart contiguous blocks of massive rock. Water from rain or melting snow also plays an important role in producing rockfalls by erosion, air slaking, and weakening of soft rocks, and by percolation of rainwater through joints. These actions remove the support for the overlying blocks of rock and can eventually initiate down slope movement. Some rock types (shales) that contain a high percentage of clay become weak and slippery when wet. The result is a reduction of static friction at the base of overlying metastable blocks. This can cause slippage, which leads to forward rotation and results in subsequent rolling, bounding, or falling of rock fragments. Equilibrium of unstable blocks in rock exposures can be upset by shock from natural

earthquakes, blasting, or movement of heavy vehicles.

Undercutting of rock slopes by stream erosion or construction excavations such as road-cuts, that remove support for overlying or overhanging rock, can result in conditions conducive to rockfalls. Talus and talus slopes are the usual natural result of numerous small rockfalls, and their constituent rocks have come to rest in metastable equilibrium, especially those rocks on the surface of the talus slope. Thus, cuts into, and construction on, these slopes can interfere with the active natural rockfall process from the cliffs above, or cause increased movement or falling of the talus material below. Certain over-steepened road-cuts or other excavations are common and dangerous areas for rockfalls.

Severity of problem

The combination of conditions that produce rockfalls is common in the hilly, mountainous, and tableland areas of Colorado. Rockfalls can result in almost unpredictable, nearly instantaneous losses of life and property, when man chooses to live or build structures in their paths without due consideration for the danger. Fortunately, many rockfall areas can be identified (see Criteria), and with proper recognition and engineering, much of the potential danger can be alleviated, if economic costs and benefits are justified and proper actions taken.

Criteria for Recognition

Many areas where rockfall may occur are relatively easy to recognize. Other areas where rockfall is a potential hazard are difficult to identify and evaluation of the degree of hazard present may be virtually impossible. Potential rockfall areas are those where relatively steep or barren cliffs rise above less steep talus or colluvial slopes. The talus slope and areas adjacent to it, occupied by larger angular randomly oriented rocks, constitute the long-term potential rockfall danger zone even though the talus may be partially overgrown with vegetation. Active rockfall areas are those showing evidence of recent falling and rock movement. Rock displaced or damaged vegetation, fresh "tracks" of rocks rolling down-slope, fresh scars on cliffs, anomalous or disoriented lichen growth on rock blocks, eyewitness accounts, and damage to fences or man-made works are some common criteria for identifying active rockfall areas. The most common difficulty with "inactive" rockfall areas is unexpected reactivation due to activities of man or exceptional natural conditions. Questionable rockfall areas should be monitored if there is the possibility that reactivation of a rockfall may take place and present a hazard to man.

Consequence of Improper Utilization

Improper utilization of rockfall areas is any use for which occasional, unpredictable, rolling, bounding, or falling of rocks could constitute a threat to life or property. Unless completely protected (see mitigation), buildings, some roads, pipelines, railroads, and most other works of man are in potential jeopardy in rockfall areas. A 3-ton of sandstone, for example, rolling downhill into a typical unprotected house, probably would destroy it, whereas this same block crossing a concrete roadway probably would do relatively little damage. A major rock avalanche could, however, destroy a roadway or a whole subdivision. In the case of costly engineered structures, expenses for mitigation of rockfall danger would likely be warranted, especially if alternative locations are prohibitively expensive. Housing, on the other hand, might easily be planned elsewhere with less expense if other potential sites are available.

Areas of potential rockfall are subject to constraints similar to those of active rockfall areas. However, if activation can be prevented, such areas could be used safely, but the cost of protection from the potential hazard can in many cases exceed the economic gain from the change in land use.

Mitigation Procedures

The simplest and most effective way to mitigate rockfall hazard is to avoid rockfall-prone areas entirely. There is no way to completely eliminate possible damage by rockfall, and practically any human use of active rockfall areas is incompatible with the risk. However, if a rockfall area is to be used, there are several ways that the hazard can be decreased. They fall into the following general classes: 1) stabilization of rocks; 2) slowing or diverting the moving rocks; 3) and physical barriers against rock impact around vulnerable structures. Rocks can be stabilized by bolting, gunite application (cementing), outright removal of unstable rocks (scaling), cribbing, or installation of retaining walls. Movement of rocks can be slowed or diverted by rock fences, screening, channeling and dams, or by concrete barriers or covered galleries. All these measures are expensive, and seldom completely eliminate the hazard. All require periodic maintenance. Stabilization is usually only a short-term solution. Complete removal of all potentially unstable rocks is usually not possible. Dams and fences fill with rock and deteriorate structurally, and concrete barriers and galleries are relatively short-lived considering their cost.

An important factor to keep in mind is that although the *place* of potential rockfalls is to some degree predictable, the *time* of failure is not. Hence, complete avoidance of areas of potential rock-fall is the most sensible mitigation measure where human lives or high property values are at stake.



Rockfall Area Along I-70 Corridor Near Lawson, CO
Photo by David C. Marlin

A description of the CDOT rockfall mitigation program is in the State Assessment section.

I-70 ... on the rocks Slide is one for the road: Huge boulders plummet from 3,000 feet above

GEORGETOWN - Boulders larger than refrigerators crashed across both lanes of Interstate 70 early Thursday, closing the main east-west route across Colorado for about eight hours.

No vehicles were trapped by the 20 to 30 huge granite boulders, the largest weighing 30 tons, that careened onto Georgetown Hill, ...

The boulders, which ranged in size from 2 feet to 9 feet in diameter, fell from about 3,000 feet above the highway, ... One semitrailer truck descending the steep hill crashed into the median barrier while swerving to avoid the falling debris, said ... Boulders stripped the tires off the semitrailer and ruptured two fuel tanks, spilling 250 gallons on the road ... A second semitrailer truck clipped the one that hit the median barrier ... the rock slide broke through 4-year-old steel netting installed on the mountainside after previous rockfalls ... The restraint system is designed to hold back rocks no bigger than a microwave oven, ... The rock slide carried trees, boulders and smaller rocks onto I-70 at about 1:30 a.m. ... Hundreds of travelers were stuck for hours as CDOT bulldozed rocks off the interstate, patched potholes created by boulders that bounced 20 feet in the air and replaced sections of the concrete barriers between lanes ... The 2-mile-long area, one of 750 dangerous rockfall zones along highways statewide, includes 15 rockfall sites with 10 chutes

... repairs to the steel netting, which uses cables and poles to hold the netting in place, would cost about \$250,000, based on a preliminary estimate. ... Cleanup crews also had to remove the fuel spilled onto the highway ...

-Deborah Frazier and Joe Garner, Rocky Mountain News,
April 9, 2004